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MAN-MADE CUTOFFS ON THE LOWER MISSISSIPPI RIVER, CONCEPTION, CO--ETC(U)
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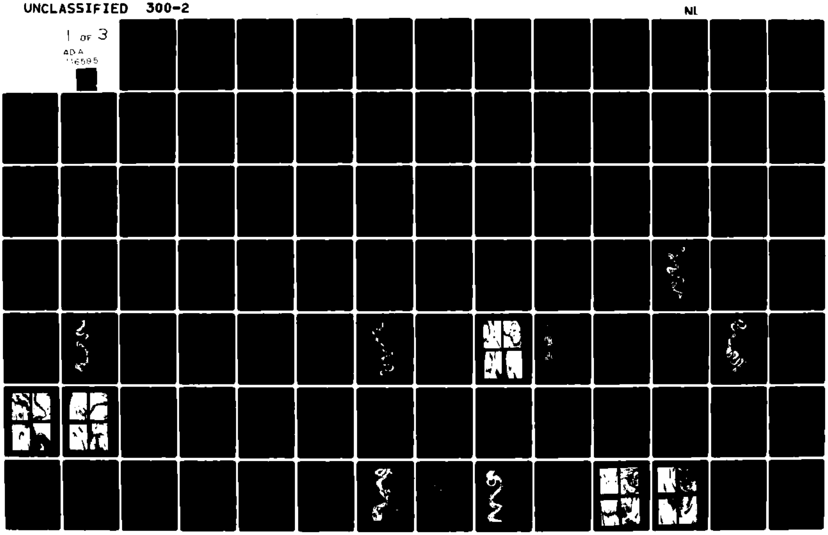

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POTAMOLOGY INVESTIGATIONS

Report 300-2

MAN-MADE CUTOFFS ON THE LOWER MISSISSIPPI RIVER, CONCEPTION, CONSTRUCTION, AND RIVER RESPONSE

by

Brien R. Winkley

March 1977

Prepared by

U. S. ARMY ENGINEER DISTRICT, VICKSBURG

CORPS OF ENGINEERS

Vicksburg, Mississippi

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POTAMOLOGY INVESTIGATIONS REPORTS

Issued Prior to and Including This Report

Report No.	Title	Date
300-1	Suspended Sediment and Bed Material Studies on the Lower Mississippi River	August 1977
300-2	Man-Made Cutoffs on the Lower Mississippi River, Conception, Construction, and River Response	March 1977

PREFACE

River shortenings (cutoffs) have been attempted on many rivers throughout the world. There are many misconceptions as to their value, construction, and the individual river's response. The cutoff program of the lower Mississippi River was one of the largest construction programs of this type ever attempted. This report reveals that as complete a knowledge of cutoffs as possible is necessary prior to any future work of this type.

The investigation reported herein was conducted by the U. S. Army Engineer District, Vicksburg. All available files of the Vicksburg District and the Mississippi River Commission were searched in order to assemble these data into one report.

The studies, comparisons, and analyses presented were made under the general supervision of Mr. J. E. Henley, Chief, Engineering Division. The report was prepared by Mr. B. R. Winkley, Potamology Section. The statements and opinions of Mr. Winkley, as well as quotations of other writers, are not intended to be construed as an official U. S. Army Corps of Engineers position.

COL G. E. Galloway was District Engineer during the preparation of this report.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
cubic yards	0.764555	cubic metres
feet per second	0.3048	metres per second
cubic feet per second	0.02831685	cubic metres per second
degrees (angle)	0.01745329	radians

MAN-MADE CUTOFFS ON THE LOWER MISSISSIPPI RIVER

CONCEPTION, CONSTRUCTION, AND RIVER RESPONSE

SECTION 1. INTRODUCTION

1.01 Objective. The purpose of this study is to reanalyze the navigation and flood channels of the Mississippi River by examining the arguments leading up to the series of man-made cutoffs, discussing their construction and illustrating the response of the system to the cutoffs.

Engineers in many countries have looked on the Mississippi River cutoff program as one of extreme success but in trying to duplicate river shortening on other rivers have often produced disastrous results. The delicate balance among the hydraulic and geomorphic factors that control river form and river flow is so complex that it is not well understood. It is necessary then that there be as complete an understanding as possible of the response of a river after a single cutoff or a series of cutoffs.

The success of the cutoff program on the Mississippi River can be partially attributed to the enormous amount of funds that have been spent in trying to hold the river in the alignment established by man. The cycle of response is still incomplete, and many of today's problems are a result of the man-made cutoffs of the 1930's and 1940's, plus a series of events, both natural and man-induced, dating back to the New Madrid earthquakes of 1811-1812.

1.02 General. The Corps of Engineers has developed flood control and navigation on many of the nation's rivers. By controlling the major rivers, most of the hazards of using floodplain lands have been eliminated; however, these rivers have reacted and are attempting to adjust to the navigation and flood control programs. It must be realized that any river is a live entity and obeys natural physical laws, and when the regime of a river is altered, there will be a response by that river. A river is also influenced by the magnitude and shape of its hydrograph and the characteristics of its alluvium. Furthermore, all the rivers in an entire drainage basin are closely interrelated and will respond to

any changes imposed eigher by man or by nature within the drainage basin.

In 1884, the Mississippi River Commission adopted a "no cutoff program." This policy was continued up to 1929 when the Yucatan Cutoff was allowed to develop in order to test General Ferguson's theories. The program of river shortening began in 1931 with just two years of observations of the river's response to the Yucatan Cutoff. As late as 1938, over 1,000,000 cu yd* in addition to original cut of 240,000 cu yd had to be dredged from the channel in order to keep Yucatan Cutoff open for navigation. Today, this troublesome reach is still responding to the problems initiated by the Yucatan Cutoff.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units and metric (SI) units to U. S. customary units is presented on page ix.

SECTION 2. THEORY OF CUTOFFS

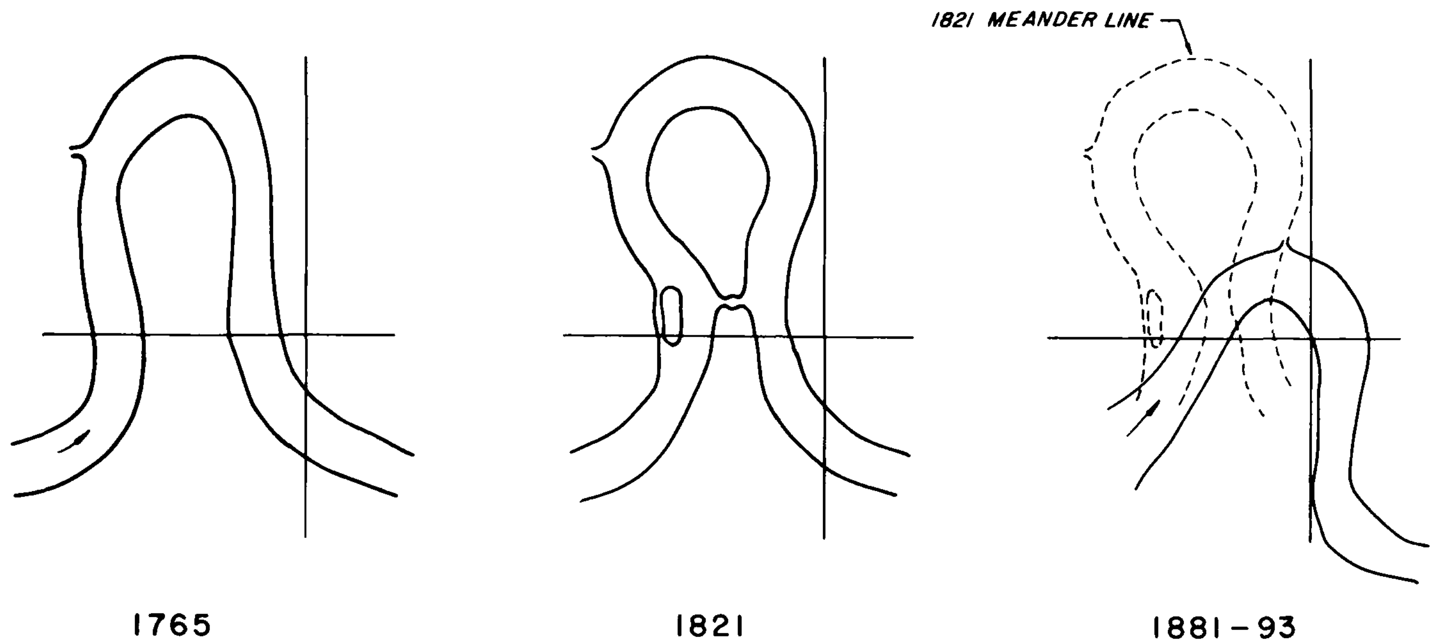
There are different schools of thought on the effects of cutoffs on river morphology. One states that cutoffs reduce flood heights, improve navigation channels, and do not cause adverse changes in the river regime. The other states that they intensify channel stabilization problems by increasing water-surface slopes and velocity, cause excessive bank failures, and, in general, upset the equilibrium of the river. Besides upsetting the slope of a river, cutoffs disrupt sinuosity and the sequence of bars and bar spacing.

No broad conclusive statement can be made to include all rivers, because each river presents its own particular problems. On any reach of any river there will be a range of energy slopes over which the hydraulic variables of the river will adjust to keep it in equilibrium. This range and thus the anticipated response can be found only by analyzing hydraulic data for each river under consideration.

2.01 Types. There are two types of cutoffs, the neck cutoff (Figure 1) and the chute cutoff (Figure 2). The neck cutoff is developed by two bends of a meander loop eroding the same bank until the narrow neck of land between the bends is cut through or as a result of down valley migration of a meander loop. This can produce a dramatic shortening of the river in that reach and usually results in much bank caving and bar building while the river readjusts its slope. A chute cutoff usually occurs as successive high-water flows develop a chute across the inside of a point bar. Chutes can also develop upstream of a neck cutoff due to head cutting or degradation initiated by the cutoff, or downstream of a neck cutoff due to aggradation and the development of a middle bar.

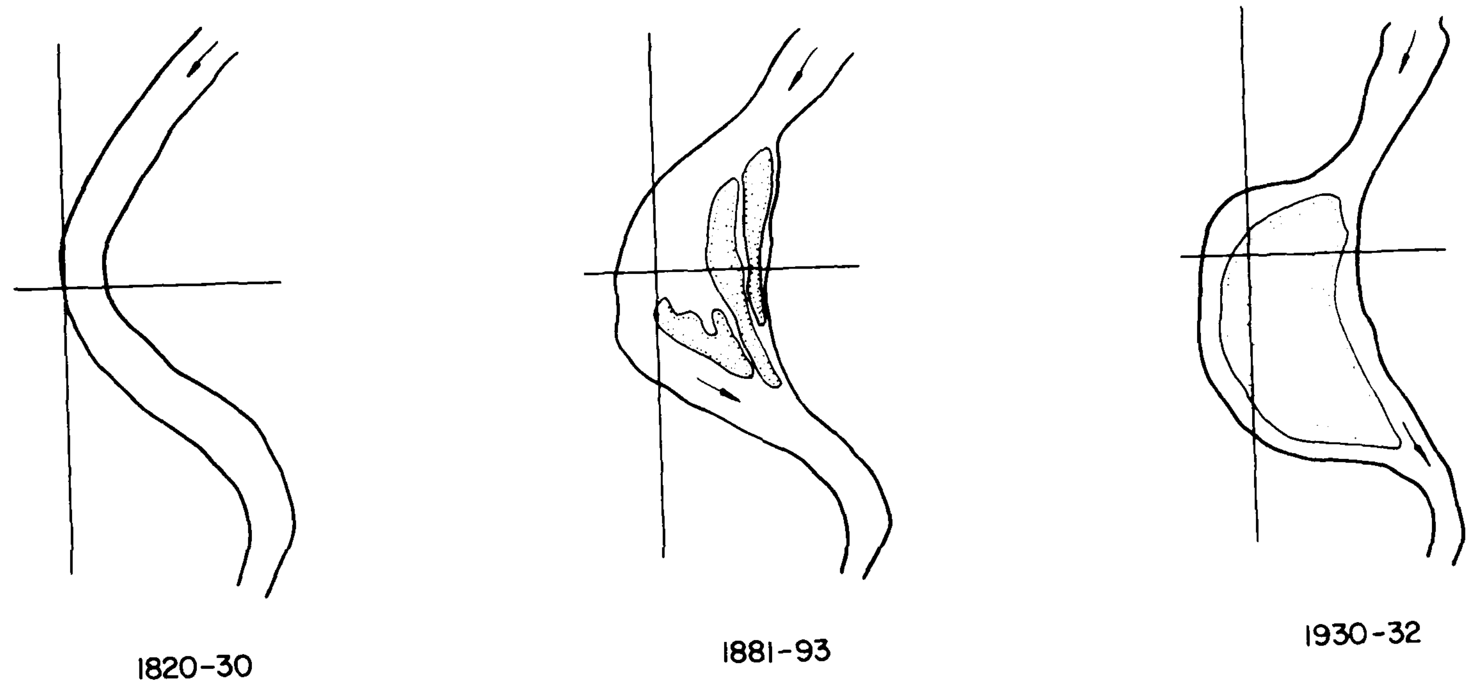
A meandering river will make both types of cutoffs as a natural means of adjusting its slope. As long as hydrographs are relatively constant over some period of time and the sediment load does not change appreciably, a meandering river will tend to keep a constant length. Figure 3 is a chart of the Lower Mississippi River's lengths over the past 2000 years. The earlier data, periods 1 through 17, were taken

Figure 1



NECK CUTOFF
(after Walters[17])

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
NECK CUTOFF AT NEEDHAM BEND



CHUTE CUTOFF
(after Walters[17])

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
CHUTE CUTOFF AT LUCAS BEND

Figure 2

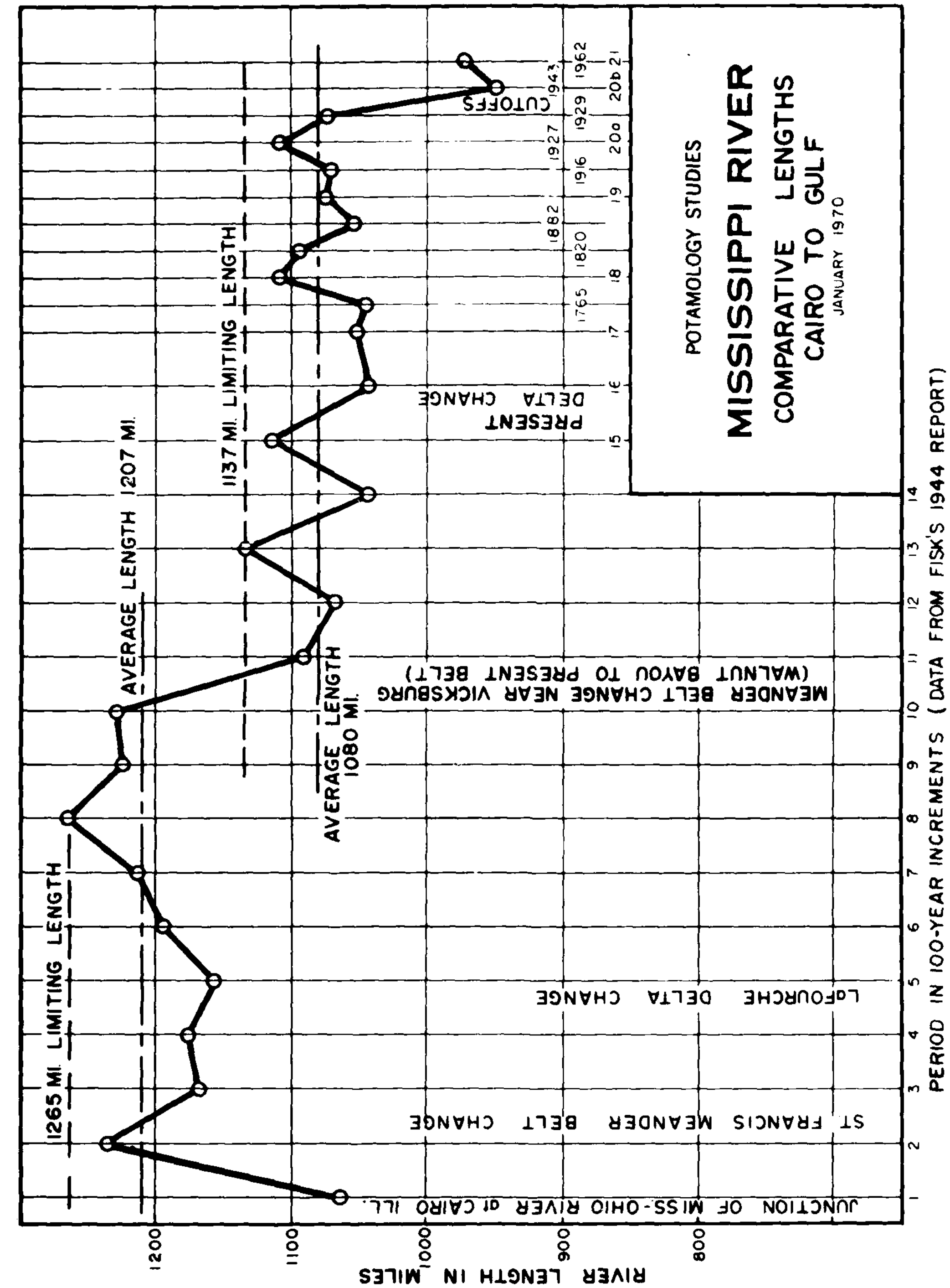

POTAMOLOGY STUDIES
MISSISSIPPI RIVER
COMPARATIVE LENGTHS
CAIRO TO GULF
JANUARY 1970
RIVER LENGTH IN MILES
PERIOD IN 100-YEAR INCREMENTS (DATA FROM FISK'S 1944 REPORT)
1265 MI. LIMITING LENGTH
AVERAGE LENGTH 1207 MI.
1137 MI. LIMITING LENGTH
AVERAGE LENGTH 1080 MI.
JUNCTION OF MISS-OHIO RIVER at CAIRO ILL.
ST FRANCIS MEANDER BELT CHANGE
LaFOURCHE DELTA CHANGE
MEANDER BELT CHANGE NEAR VICKSBURG (WALNUT BAYOU TO PRESENT BELT)
PRESENT DELTA CHANGE
CUTOFFS

Figure 3

.om H. N. Fisk's report[1]. Note that the river lengths remained fairly constant while the river slope was controlled by a specific meander belt or delta location. Major length, thus slope, adjustments occurred only when there was a change in meander belt and/or delta location.

2.02 Theoretical Response. In 1947, E. W. Lane[2] described a river's reaction to a single cutoff, an understanding of which might clarify a few points for the reader:

> For the general case, it may be assumed that a cutoff occurs in a single bend in a stream with erodible sand or gravel bed, where the stream before the cutoff was not changing its flow capacity substantially from year to year.... The bed, ABCD, of the river after the cutoff is reproduced in Figure 4 and also

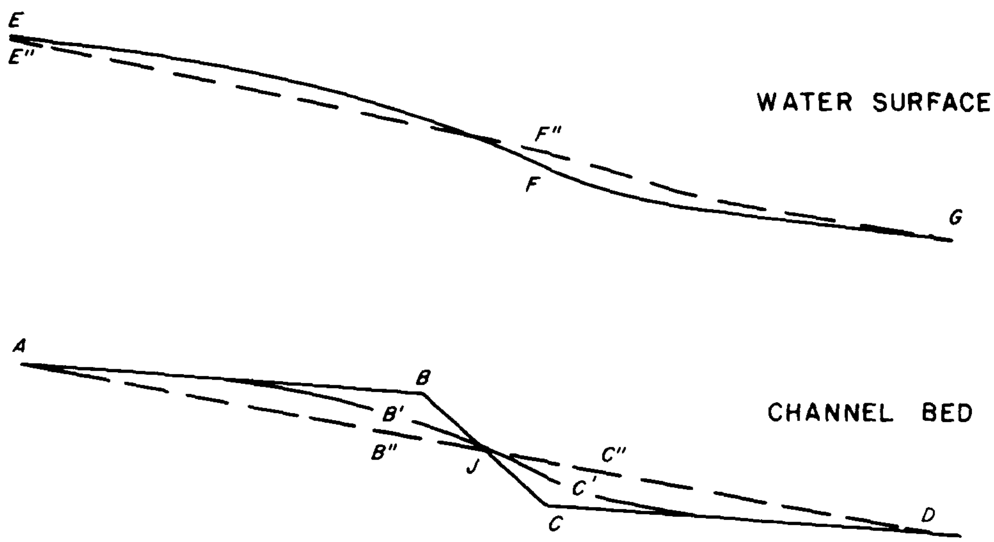


Figure 4. Effect of cutoff in an erodible channel (after Lane[2])

> the water-surface profile EFG. Consider first the reach above the cutoff. The slope and velocity of the water above the cutoff is increased as compared to that existing before the cutoff was made, and the stream can carry a greater load than it was carrying. Because the stream at this point has a capacity to transport material in greater amount than the load brought down to it from above, the water picks up material from the stream bed and carries it downstream. Below the cutoff, however, the slope and velocity of the river is unchanged, and it is able

> to carry continuously only the amount carried before the cutoff. The excess over the load carried before the cutoff, which was taken up from the bottom upstream from the cutoff, is, therefore, deposited below the cutoff. This excess is not dropped immediately but is deposited in gradually decreasing quantities downstream from the cutoff. This results in a profile of the bed AB'C'D, which causes some increase in slope downstream from the cutoff and a spreading of the deposits still further downstream. As the movement continues, the bottom downstream from the cutoff continues to be raised, and this effect also extends farther and farther downstream as shown by the profiles AB"C"D and E"F"G. The cutting down of the stream from the cutoff gradually increases in depth and extends farther upstream causing a lowering of the water-surface elevation in this section to an elevation lower than that which would result from the cutoff if the bottom was non-erodible; the lowering effect also extends farther upstream. The raising of the bottom below the cutoff causes a raising of the water level downstream from the cutoff which extends a considerable distance downstream. After the river has had a long period of time to adjust itself, the maximum lowering above the cutoff occurs just upstream from the cutoff and approaches half the amount of the increased fall due to the cutoff. The maximum rise of water surface occurs just below the cutoff and approaches half the increased fall.

Today an increase in height of flood flows is being experienced in the reaches downstream of the cutoffs in the Lower Mississippi River. Because so many cutoffs were constructed and so many chutes were developed, long reaches of river are responding as if they were associated with a single cutoff. In Figure 4, the reach AB is synonymous with the Memphis District, BC with the Vicksburg District, and CD with the New Orleans District.

So much alteration was done that it is impossible to consider any one cutoff as a single entity. Furthermore, the rate of response of a stream is proportional to the energy slope, and because the lower river is flat, many decades may pass before the final adjustment has been attained.

2.03 <u>Cutoff Advantages and Disadvantages</u>. E. W. Lane[2] states:

> From very early times it has been believed that the height of floods in crooked rivers could be reduced by cutting off the bends and straightening the channel in order that the water would flow faster and not rise to such great heights. Although the results were usually beneficial, in some cases where they have been used, cutoffs have increased damage in one locality while reducing it in another, thus possibly causing a net damage rather than a benefit...
>
> The changes which take place in erodible channels due to cutting off bends may be divided into two classes: (1) immediate changes, and (2) long-period changes. The first of these occurs immediately or within a short time after the cutoff is completed, and long-period changes are those which take place gradually over a period of considerable length, in some cases over a very long period of years.

Another problem is the disruption of sequence of alternate bars and sediment transport. In analyzing the response of any one cutoff, it must be remembered that the variety of slopes, soils, and suballuviums result in a wide variation of the channel response.

In 1930, according to H. B. Ferguson[3], then a Colonel and Division Engineer of the South Atlantic Division:

> The unfavorable effects (of cutoffs) are:
>
> 1. Increase current above.
> 2. Increase sand deposit below.
> 3. If not foreseen and guided, may make wrong curvature and generally upset river.
> 4. If dredging is not done, there may be difficulties for navigation at the period when old channel is about equal to new channel.
>
> The favorable effects (of cutoffs) are:
>
> 1. Each cutoff eliminates two crossovers and facilitates the movement of sand.
> 2. Increases mean stage slope. Induces scour above and maintains effective velocity after enlargement above is completed.
> 3. Shortens navigation channel.
> 4. Increases high-water slope.
> 5. Gives less sand if bed is dropped several feet.
> 6. Gives basin for deposit of sand in old bend.
>
> Precautions necessary are:
>
> 1. Make cutoffs at lower end first, or after channel

below is prepared to carry away the sand.
2. Lower riverbed about 3 ft below any proposed cutoff before making cutoff.
3. Revet or dredge above cutoff.
4. Keep channel below open by dredging.

The Lower Mississippi River in its natural state took from 30 to 80 years to recover from one cutoff, i.e. to regain widths, bar sequence, and hydraulics. A cutoff occurred naturally every 7-10 years over an 800-mile reach or 0.0015 cutoff per mile per year. Under the guidance of General H. B. Ferguson, cutoffs were made at the rate of 0.0032 per mile per year or 21 times more frequently. Since only 40 years have passed; the river has not yet had time to complete its response. Also in the 1930's, the river was still in a transition state, adjusting to the previous 120 years of man's and nature's activities. The river may never fully adjust to the changes imposed because of the current stabilization program.

Many engineers in the past several decades, as well as many currently working on rivers, believed that the capacity of the river to carry floodwaters could be greatly increased by remolding its bed and altering its alignment to provide an unobstructed and more direct, deeper, and more efficient channel. It was also believed that at the same time and by similar methods, navigation conditions on the river could be improved.

In 1962 Mississippi River Commission report,[4] the advantages of the cutoffs on the Mississippi were:

> Major reductions in flood profiles resulting from this improvement work, together with some increases in levee grades, eliminated the requirement for a floodway on the west side of the river between the Arkansas and Red Rivers. The lessened frequency and duration of floods has made possible reclaiming or permitting higher usage of large land areas in the St. Francis, White, and Yazoo River backwater areas and also other lands along the main stream, which do not have the benefit of levee protection. The shorter length of river, together with an expanded bank stabilization program, has resulted in less maintenance dredging. Despite a slight increase in slopes and velocities, the net effect on navigation

> has been to shorten trip time. However, the increased velocities were, no doubt, influential in advancing the development of high-powered towboats. The elimination of bendways of short radii in the long meander loops has lessened the length of channel to be stabilized.

Many of these "advantages" have now been lost as the river further responds to the cutoffs and other work.

The same report stated that the disadvantages of the cutoffs were:

> Cutoffs have disadvantages as well as advantages, though some may be of only temporary nature. Problems arise other than those attendant to the development of the cutoff itself. If the old bendway deteriorates prior to the time the river regimen adjusts itself to the new slope, high velocities through the cutoff may require double tripping of tows or conversely, a major dredging effort may be required to keep the bendway open while the slopes are adjusting. Levees may have to be set back, resulting in severance of farm units and disassociation of the point from the state to which it was attached. Cities and communities may be removed from the main channel of the river requiring, in some cases, the maintenance of the old channel as an access channel to the harbor of the divorced community. Additional dredging is usually required while the river is adjusting to the new slopes. Existing revetment may become inactive and additional revetment required to conform with the new regimen of the river. Structures located upstream, whether of a navigation or flood control nature, docks, water intakes, or similar improvements may be adversely affected by the lowering of both the high-water and low-water planes. Finally, public opposition may be expected because of real or fancied concern of the effects and side effects of cutoffs.

Many of these "temporary disadvantages," plus others, still persist in the river.

SECTION 3. COMMENTS LEADING TO THE CONSTRUCTION OF THE MAN-MADE CUTOFFS ON THE LOWER MISSISSIPPI RIVER

3.01 Favorable Comments. In his report on control of Mississippi floods, General H. B. Ferguson[3] made the following comments:

> The capacity of the river to carry floods may be increased: (1) by shortening the river; (2) by restricting or avoiding crossovers; (3) by permitting over bank flow to be continuous on either bank; (4) by shutting off secondary channels; (5) by checking erosion of sand bars or banks; (6) by deepening the maintained low-water channel where it coincides with the high-water channel....
>
> As the flat slope is carried upstream, the difficulties of controlling this lower part of the river will decrease.... While considering a plan for expediting the movement of flood waters in the lower reach, it must be borne in mind that in treating the upper river above the mouth of the Arkansas we must, for the present, pursue an exactly opposite policy. The bends should be allowed to continue to lengthen there, and all works, except just below Cairo, should be laid out with this constantly in view....
>
> "Corrective dredging" means dredging that is done for the accomplishment of corrective measures, or for the obtaining of an hydraulic condition that will be favorable to what is desired in the whole plan....
>
> The kind of dredging now being done on the Mississippi is a prime example of maintenance dredging. Dredging is done at the crossovers in order to keep a channel sufficiently deep for navigation. These places are so located that they usually fill up each year. The dredging contemplated within the program and referred to as "corrective dredging" is not that kind of dredging. When, in a river, we find a section of a channel that maintains a more or less constant depth and width which it has secured by the process of erosion, there is great probability that dredging at this locality will, to a certain extent, leave a permanent enlargement. This must inevitably follow in the fact that the current required to scour is greater than the current required to prevent deposit. The exact extent to which the enlargement can be carried and remain permanent can be determined only by trial....
>
> Because of the enormous amount of sand the question of its disposal is important....

> The main river below Old River will hold vast quantities of sand without injury to any interests provided the Atchafalaya River is slightly enlarged....

Today the lower river below Old River as well as the Atchafalaya River is aggrading.

General Ferguson undertook one of the largest construction jobs ever attempted. The laws of physics as pertain to rivers and sediment movement are not well defined today, and in 1932, the knowledge was certainly even more incomplete. At that time, engineers were not as concerned with the movement of sediment as they are today.

The cutoff program proposed by General Ferguson was considered to be a new approach in Mississippi River flood control. His justification for a series of cutoffs was based upon the following premise:[5]

> The new approach was based upon recognition of the fact that this river did not, strictly speaking, flow in a self-accumulated bed of alluvium wherein it could assume the characteristic graded profile of a mature stream of established regimen. It was recognized that at numerous points it had, in its meandering, encountered the stable bluffs which border the alluvial valley and had elsewhere encountered, within its bed, deposits of tough, nonerodible materials. The presence of these recalcitrant elements, together with man-made bank revetments which have similar effects, had at many points deprived the stream of its bed-mobility, had disordered the normal flow, and had made humps in the slope of the profile of the water surface, causing harmful deposits in the reaches affected. Interference with navigation and increase of flood heights had resulted.

The humps referred to are natural to an alluvial river and are a result of sediment movement and geological controls.

The basic objective of the cutoff program was to direct the river's energy for channel improvement purposes, i.e. a straighter alignment. This was to increase flood wave propagation through the affected reaches and deepen the channel for navigation. Corrective dredging was used to guide the river's energy to accomplish either erosion or deposition where desired. Sand dikes were constructed from dredged materials to assist in closure of the cutoff bendways.

General Ferguson believed that the river would adjust to the cutoffs in a year or so. Forty years later, the adjustment continues. Ferguson ignored several aspects of river response that are today recognized as significant. These include geometry, bed and bank material, valley slope, sediment movement, and the transition state of the river, reacting to the previous 100 years of activity.

In 1946, W. E. Elam[6] reports:

> Too much credit cannot be given Major General Brown (formerly Chief of Engineers) and Major General Ferguson for adding cutoffs to the flood control plan where the entire valley officially opposed their use.

Such statements as this aroused concern that the cutoff program might have been a project motivated more by selfish interests than by sound judgment. As revealed in the next section, many of the engineers in the Mississippi River Commission prior to 1930 could see the probable response of the river to cutoffs and therefore were against the program and in favor of the "Jadwin Plan," which intended to prevent cutoffs. Many engineers advocated trying out cutoffs "gradually" and "with caution."

In 1947, according to G. H. Matthes,[7] an engineer with the Mississippi River Commission:

> General Ferguson's conception...was sound as it aimed at preserving hydraulic gradients so as not to exceed those prevailing in stretches where the river was known to possess an "orderly channel."

This term, "orderly channel," was applied by General Ferguson to designate a channel having mild curvatures, free from islands and back channels, and whose shifting tendencies involved no excessive bank caving and bar building. This trend of thinking does not consider variation in valley slope, alluvium, and tectonic activity.

Matthes also states:

> The Mississippi River Commission program on cutoffs was to shorten the river, without, however, straightening it. Mild curvature was held to be essential for preserving a deep navigable channel as well as for effecting such stabilization as might be consistent

> with the meandering nature of an alluvial river....
>
> General Ferguson, upon taking office at Vicksburg on June 15, 1932, found practically his entire staff strongly prejudiced against cutoffs, and, in addition, this prejudice had become extended to include many state officials and engineers on levee boards...on June 17, 1932, two days after he assumed office, in the presence of the writer (Matthes) drew the center line and the width of the right of way on a map, and dictated "to have work initiated this summer".... If any surveys or boring had been made previously, these had not come to the writer's attention.

(See Section 7 for a discussion of continual work necessary to make the cutoffs effective.)

3.02 Unfavorable Comments. In 1859, Humphreys and Abbot[8] reached an unfavorable conclusion on cutoffs and in summation stated that further discussion was not necessary since it was not practicable to make artificial cutoffs.

Major General Edgar Jadwin states in House Document 90, 75th Congress:

> Artificial or natural cutoffs shorten the reach where they occur and by increasing the slope and velocity produce a local lowering of the flood stage. However, the increased velocities immediately cause excessive bank caving either in the reach or near it, and the river eventually lengthens itself with new bends. The changes in the channel cause great damage and expense....
>
> Low-water navigation in any stretch is likely to be temporarily destroyed by bars created by the excessive bank caving caused by a cutoff. The method is too uncertain and threatening to warrant adoption....
>
> It is advisable to adhere to the present policy of preserving the river generally in its present form and not to undertake a plan of flood control or of improvement for navigation that involves the formation of cutoffs....
>
> The confinement of flood flows by levees had substantially raised the flood heights. There is a theory that an alluvial stream tends to make a channel to accommodate itself. Even if this theory be correct, it does not solve the problem, because the floods must be controlled before there has elapsed enough time for such

a theory to work out. The water must be provided for now, and after extreme stages are provided for, a possible future enlargement in size of channel is of little practical value. A gradual filling of the banks of the river within the levee and growth of the islands tends to counterbalance scour in the channel proper.

Many river engineers, both civil and military, insisted that any benefits derived from a series of cutoffs would soon be nullified by the river's action.

During the 1930-1960 period engineers apparently did not appreciate nor did they understand the time factor necessary to effect results from a gross series of cutoffs. It is interesting to note that almost every engineering report on the river since 1850 has been anticutoff, and gave numerous reasons why cutoffs should not be permitted on the Mississippi River. For example, a 1932 U. S. Army Engineer Waterways Experiment Station report[9] states:

> Item e: Any cutoff across Ashbrook Neck should be studiously avoided because of its probable effects on upstream velocities and downstream direction of currents.... Cutoffs at Caulk and Tarpley Necks can do little material good in reducing stages where desired, and although no objection can be seen to letting Caulk cut through by itself, there seems no valid reason for encouraging it.
>
> Item f: The cutoffs between Vicksburg and Lake Lee would be valueless and extremely expensive to dredge. No further thought should be given to them. [This relates to Marshall, Willow, and Sarah cutoffs.]
>
> Item g: A cutoff at Diamond Point would have several good features and no apparent bad ones. Further tests will definitely indicate the advisability of assisting, or allowing it to occur naturally. As to the other three below Vicksburg: Yucatan is already accomplished; a cutoff at Natchez [later called Giles] would be of dubious value in an already fairly stable reach; and at Esperance [later called Glasscock] of no value at all.

SECTION 4. "FERGIE, GO FIX THE RIVER"

When the 1927 flood overtopped levees built to the maximum expected floods heights, men began to look for other methods of river improvement. The entire nation took up the problem, and cutoffs were debated again. Brigadier General H. B. Ferguson made a study of the Mississippi River referred to previously and in 1930 outlined a program of river improvement by means of cutoffs and dredging (see paragraph 7.04). In support of the Ferguson approach, a natural cutoff at Yucatan Point in 1929 had been observed to have had no serious effects on the river. In addition, opposition to the Boeuf-Tensas Floodway had forced the Mississippi River Commission to eliminate it from the 1928 plan and to seek some means of carrying the entire flood discharge down the leveed channel.

It is said that in 1932 when General Ferguson was called in by the Chief of Engineers, Major General Lytle Brown, and was told he was being appointed President of the Mississippi River Commission, they sat and smoked their pipes in silence for a long time. General Ferguson finally asked, "Well, do you want me to write a book, or fix the river?" More silence, more smoking. Then General Brown said quietly, "Fergie, go fix the river."[10]

In 1945, R. K. Stewart[11] stated: "Ferguson fixed the river, transforming it into a quite different stream, in the face of long-standing precedent and vigorous opposition."

The report cited above concludes: "...the success of Gen. Ferguson's plan is now history." The aftereffects of the cutoff program will also be part of future river history. In order to regain a regime condition, all geometric parameters of the Mississippi must continue to adjust to the new flow conditions and sediment loads, a process that will extend far into the future. As a further complication, bank stabilization has fixed the plan geometry of the river so all adjustments must be made within bank and the sediment must move down the channel or be confined within levees.

SECTION 5. VALLEY HISTORY THAT INFLUENCED THE RIVER'S CHARACTERISTICS

5.01 Geologic History. The characteristics of the Mississippi River, as well as the local response to cutoffs, are closely related to the geologic controls in the river valley. These controls include rock outcrops, gravel and coarse alluvium concentration, clay plugs, the general stratification of soils, valley slope, and the fault zones resulting from tectonic movements.

Much has been written on the geologic history of the Lower Mississippi Valley. One of the most complete records was assembled by Fisk,[1] in which he explains that the current hydrographic system became established after the present stand in sea level was reached and the Mississippi River was diverted through Thebes Gap to join in the Ohio River at its present junction. As he further states, the Lower Mississippi has shown no tendency to aggrade or degrade its channel since the Thebes Gap diversion and has maintained a constant overall valley slope. Also, Fisk dates the current meander belt at 2000± years old and has provided reasonable documentation of river location in 100-year increments. Recent work by R. T. Saucier[12] indicates a variation in the time of activity of the present meander belt, but in either case the sequence of events remain the same, only the rate of occurrence changes.

According to B. R. Winkley,[13] because of flow adjustments and meander belt and delta location shifts, the riverbed had not reached a condition of regime until approximately 500 years prior to man's first attempts to control the river in the 18th century. During this 500-year period, the river averaged 14 cutoffs per hundred years and seemed to take 30-80 years for a local adjustment to any cutoff. The wide variation of adjustment time was a result of slope variations, the number of cutoffs in a particular reach, soil variations, and possible tributary action.

Even though the river might be considered as "in regime" for this 500-year period, it is believed that the valley was aggrading. The

entire valley, in a natural state, was a delta from Cape Girardeau, Missouri, south. The river could contain only about 1,000,000 cfs between its top banks, and the balance of flood water plus much of the lower flows was released over bank and through the numerous outlets. The sediments associated with these outflows were shaping and filling the St. Francis, Yazoo, Boeuf, Tensas, and Atchafalaya Basins.

The lower river as well as the entire lower valley has been in a state of transition for the past 200 years. It has never had a chance to adjust to one major flow variation before another has been imposed. Thus, it is virtually impossible to determine the impact of a single event and its influence on the Lower Mississippi River.

5.02 Two Hundred Years of Man's and Nature's Activities. During the past several hundred years of uniform conditions, the river built today's meander belt and was gradually filling in the delta below Cape Girardeau.

In the early 1900's, J. A. Ockerman,[4] Chief of the Engineering Design Branch of the Mississippi River Commission, stated:

> Any study of the changes in channel elements must bear in mind that these elements vary widely with contemporary conditions. For example, a severe flood may scour out the channel beyond normal capacity of the river to maintain it. On the other hand, an uninterrupted series of low-water years is accompanied by some degree of channel deterioration. Observations made during, or immediately after, such an abnormal period are likely to be misleading. For this reason, a study of this sort must include not only the surveys (and hydraulics) themselves, but also contemporary river history.

The river of the 1700's has apparently adjusted to postglacial flows and sediments, to the present sea level, to a single-channel meandering stream condition, and to a top bank flow of from 1,000,000 to 1,200,000 cfs. Starting with the New Madrid earthquakes of 1811-1812, a series of events were imposed on the river that kept it in a constant state of transition. The more noticeable events are listed below, not necessarily in chronological order. The aftereffects of some of the following are continuing today:

a. The 1811-1812 earthquakes with an epicenter near New Madrid, Missouri. This event caused excessive bank caving and increased sediment activity, causing bar growth and navigation problems. The earthquakes also created a negative picture of the river and its behavior just as man began using it.

b. Levee building began in 1719 and was followed by a continual increase in levee length and height; Figure 5 shows this continual increase in levee height and the accompanying increase in stages at the Natchez gage. In Figure 5, a "crevasse" is a levee failure, one or more of which occurred during each major flood prior to 1929. An "outlet" is a diversion channel that drained various size flows from the main channel into the numerous basins on either side of the Mississippi River. During floods, flows through the lower Mississippi valley were similar to those indicated in Figure 6.

c. With the levees, all outlets were closed, confining an extra 600,000± cfs of flow to the river during floods and lesser amounts at lower stages. This affected not only the Mississippi River but also all the distributary streams in the St. Francis, Yazoo, Boeuf, Tensas, and Atchafalaya Basins. Some outlets diverted flows at both high and low stages. In the natural Mississippi River channel, sediment distribution began at the northern end of the lower valley and was distributed both downstream and laterally over the floodplain. Today, sediment is confined to the area between the levees, and for all in-bank flows the sediment movement down valley has increased in magnitude. Figure 7 shows the cross valley profile of the 1882 flood.

d. The wood-burning steamboats of the 1800's cleared thousands of acres of vegetation from the streambanks. This, coupled with land clearing for agriculture along the natural levees, resulted in instability of the riverbanks. Runoff from these cleared lands plus the added bank caving increased the sediment load.

e. The "no cutoff" program, formulated in 1884, initiated a large-scale bank protection program, which prevented normal migration. Limited funding forced bank protection only where the need was the greatest. Thus, in many reaches an alignment developed that may not have had the best geometry for sediment movement or for flood passage.

f. Dredging for navigation began in 1895; alignment dredging began with the cutoff period (1932). As a result, millions of cubic yards of extra sediment were added to the river channels, probably hastening a downstream shift of the coarser sediments, which created some of the problems below Natchez, Mississippi, on today's river.

g. The use of training structures (dikes) began in the late 1800's

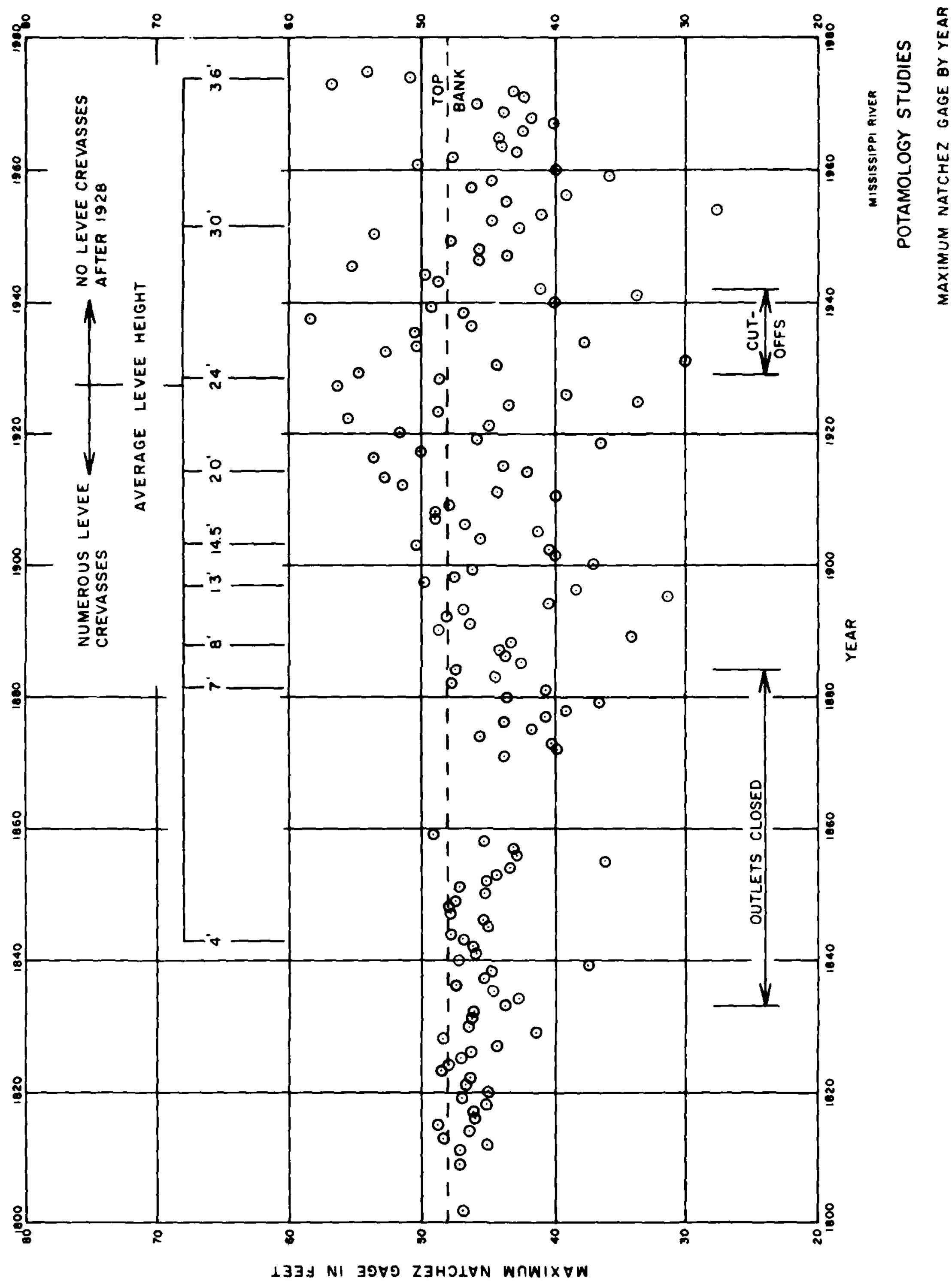

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
MAXIMUM NATCHEZ GAGE BY YEAR
NUMEROUS LEVEE CREVASSES
NO LEVEE CREVASSES AFTER 1928
AVERAGE LEVEE HEIGHT
4'
7'
8'
13'
14.5'
20'
24'
30'
36'
TOP BANK
CUT-OFFS
OUTLETS CLOSED
YEAR
MAXIMUM NATCHEZ GAGE IN FEET

Figure 5

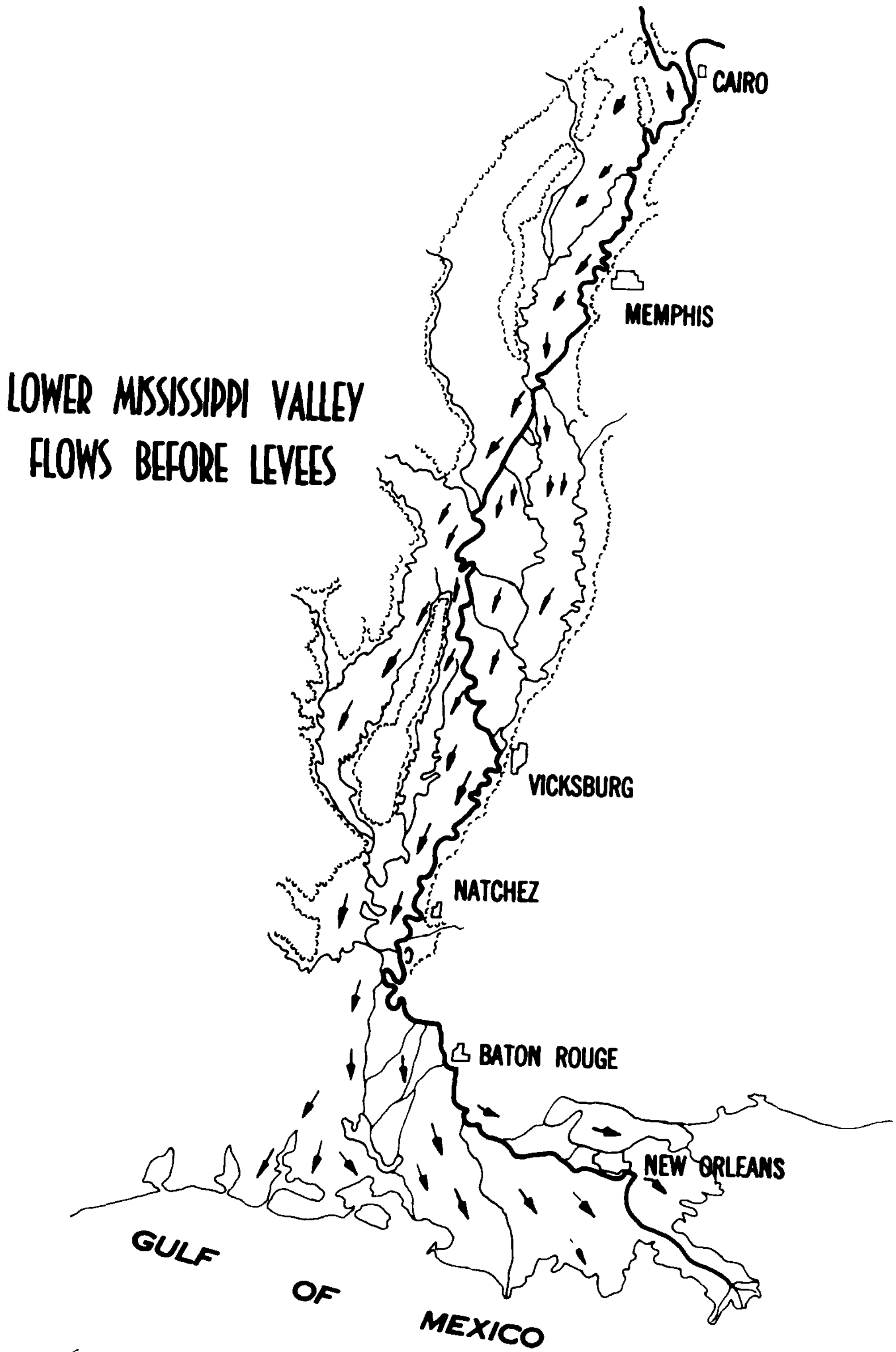
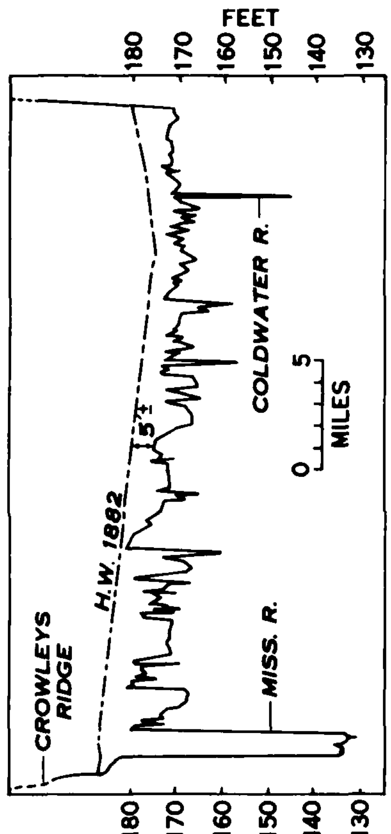
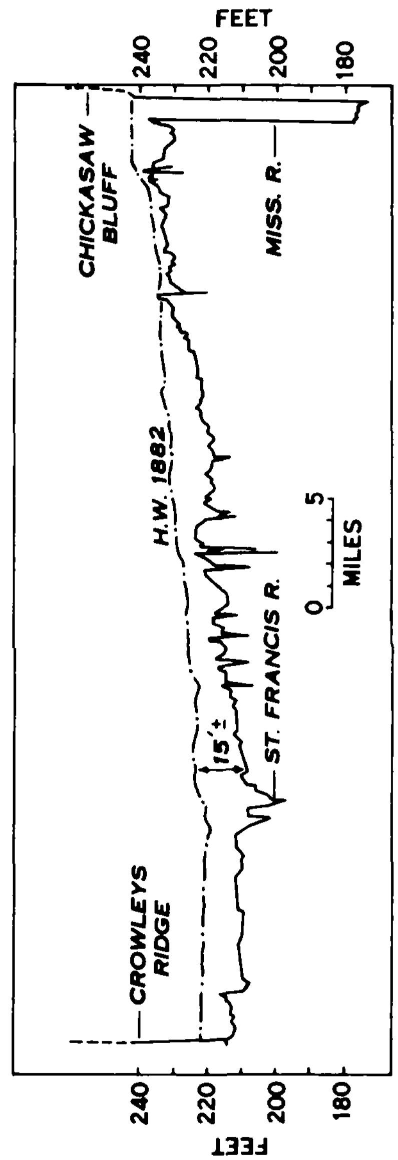

LOWER MISSISSIPPI VALLEY
FLOWS BEFORE LEVEES
CAIRO
MEMPHIS
VICKSBURG
NATCHEZ
BATON ROUGE
NEW ORLEANS
GULF
OF
MEXICO

Figure 6



Trans-Alluvial Level Line From Helena, Ark., to the Eastern Valley Wall in the Yazoo Basin (after Davis, 1882).

1962 RIVER MILE 662



Trans-Alluvial Level Line From Fulton, Tenn., to Crowleys Ridge in the St. Francis Basin (after Davis, 1882).

1962 RIVER MILE 780

Figure 7

but were mostly temporary structures made of wood piles until the early 1960's. Since that time, all dikes have been constructed with quarried stone. The shape and position of these structures has had some effect on sediment transport, navigation depths, and flood heights, but the amounts are at best debatable. Much analysis is needed on the effects of training structures before any conclusions can or should be reached.

h. During the 1930's and 1940's, the river was shortened 152 miles by cutoffs and another 55 miles, from 1939 to 1955, by chute development. The cutoffs occurred over a 13-year period and probably had more of an immediate noticeable effect on the river than any single event with the exception of the 1811-1812 earthquakes.

i. During the period of cutoff construction and for 10 or more years after this period, over 1,700,000,000 cu yd were dredged in an effort to align the river with the cutoff channels and maintain navigation. Instead, this grossly changed flow conditions and in many reaches resulted in divided flow conditions with their associated problems.

Each of the above events has had some effect on the river, but these events have overlapped in sequence and in time. Accordingly, there is no way to evaluate the cause and effect of each individually even if sufficient data exist for such a study.

5.03 Historical Cutoffs. Table 1 is a listing of all known cutoffs between 1776 and 1884. These did not occur or develop instantaneously but took many years to become fully active.

The following extract is from an 1851 Congressional Report:[4]

> The cutoff at Raccourci, made three years ago, is not yet washed out, by one-third, to the usual dimensions of the channel; though, by reason of the contraction of the waterway, the velocity of the current at that point is greatly accelerated.

The 18 cutoffs (Table 1) made over a 108-year period shortened the river 218 miles and were spread over 640 miles of river, yet the river in 1884 varied only 8 miles in total length from the river of 1776. The 16 cutoffs from 1929 to 1942 shortened the river 151.9 miles during a 13-year span. These cutoffs were made over a 503-mile reach shortening this reach 30 percent in length.

The essential question to be answered is that if the river took from 30 to 80 years to recover from a single cutoff and had averaged

Table 1

List of Cutoffs, Mississippi River Below Cairo, 1776-1884

Cutoff	Miles Below Cairo	1962 AHP* miles	Year Cutoff Occurred	River Length Reduction by Cutoff, miles
Needham's	135	820	1821	11
Centennial or Devil's Elbow	204	754	1876	15
Commerce	270	690	1874	10
Bordeaux Chute	279	680	1874	7
Montezuma	314	656	1817	11
Horseshoe	320	650	1848	9
Napoleon or Beulah Lake	400	584	1863	10
American	497	525	1858	11
Grand Lake	517	508	1817	10
Bunches Bend	524	505	1830	12
Terrapin Neck	576	462	1866	16
Yazoo	596	442	1799	12
Centennial Lake	601	438	1876	6
Davis or Palmyra	623	422	1867	19
Waterproof	680	377	1884	12
Homochitto	753	322	1776	13
Shreves**	771	303	1831	15
Raccourci**	775	299	1848	19

* Above Head of Passes.
** Man-made cutoffs.

only 14 per 100 years, in its natural state, then how long will it take to recover from 16 artificial cutoffs in a 13-year period over a much shorter reach of river. The answer must be based in part on conjecture, but considering an average length of time for the river to recover from this dramatic shortening, it would take at least 55 years or until 1997. This supposition is based on the river's being allowed to regain its length, sinuosity, and bar spacing. However, this has not been allowed, making the 55-year estimate even more of an unknown. The artificial cutoff or "dramatic shortening" has been hailed in literature and by governmental and private agencies worldwide as a successful method for improving flood flows on any stream. What has been overlooked, however, is that the long-term response of a river to significant shortening by cutoffs is often a period of instability, with considerable bank

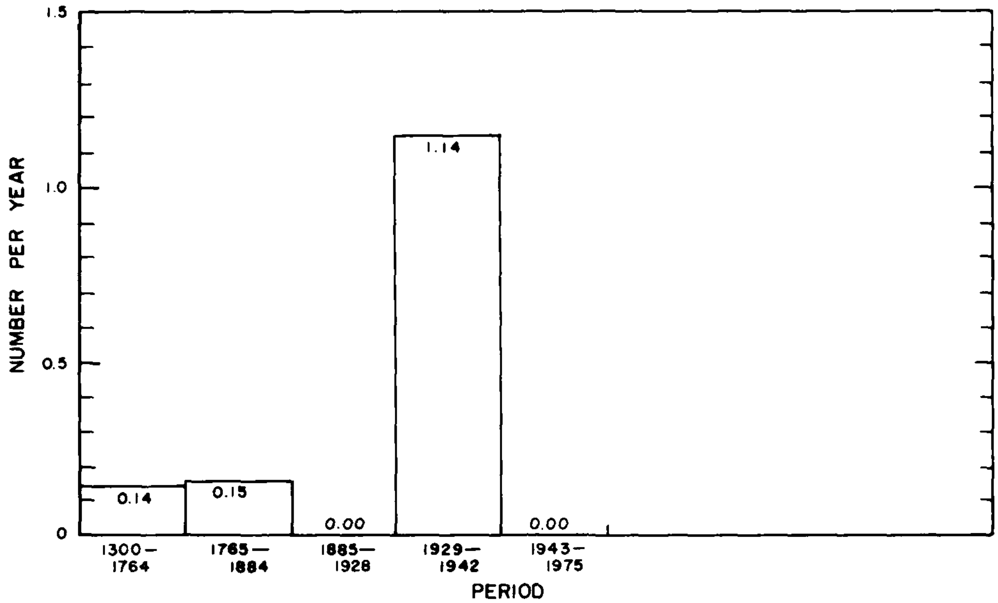
erosion and lateral shifting before stability is restored. The direction and magnitude of change and the time involved in reaching a new equilibrium are largely dependent on the geology, sediment load, and hydraulic geometry of the particular stream in question.

Rivers in their unaltered natural surroundings are balanced systems with respect to their drainage basin geology and hydrology. This balance of equilibrium is easily upset by man's drainage basin activities, including urbanization, landclearing, highway construction, and agriculture and tree harvesting. Each of these increases runoff and erosion, which alters the drainage basin topography and would eventually cause hydraulic and geometric changes in the stream channels. Man's activities on a river, such as navigation and flood control works, have an immediate effect on channel geometry, especially the construction of cutoffs as will be established in subsequent discussion.

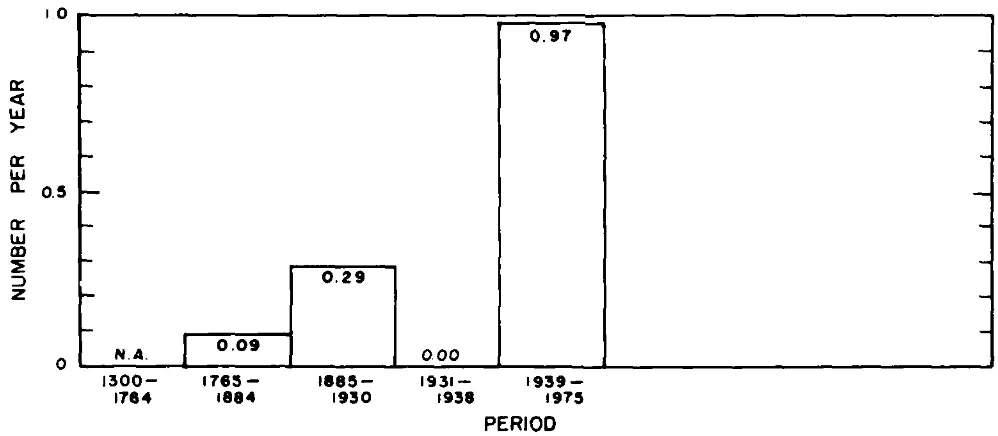
5.04 Rate of Cutoff Occurrence. Figure 8 shows the number of cutoffs per year for both the neck and the chute cutoff. During the five hundred years prior to man's influence on the river, only 0.14 neck cutoffs occurred per year, and no record of the occurrence of chute cutoffs exists for this period. In the early period from 1765 to 1884, 0.15 neck and 0.09 chute cutoffs developed per year, or a total of 0.24 cutoffs per year. The Mississippi River Commission entered a cutoff prevention period from 1884 to 1929, when Yucatan Cutoff was allowed to develop; however, during this period of no neck cutoffs, the number of chute cutoffs rose to 0.29 per year.

General Ferguson's realignment program increased the cutoff rate to 1.14 per year, almost 8 times the normal rate. Neck cutoffs have not been allowed since 1942, but chute cutoffs have been constructed or have developed at the rate of 0.97 per year, up almost 10 times the normal rate.

This partly explains the consistency of river length during the past 30-40 years. The major increase in slope that resulted from the cutoffs of the 1929-42 period is the principal cause of recent river navigation and flood control problems.



NECK CUTOFF



CHUTE CUTOFF

MISSISSIPPI RIVER

POTAMOLOGY STUDIES

NUMBER OF CUTOFFS PER YEAR

Figure 8

SECTION 6. CONSTRUCTION OF THE CUTOFFS

An alluvial river with bed-load sediments must have a sinuous geometry in order to be self-maintaining. Without sinuosity, the sediment transport variations of a constantly changing hydrograph cannot be balanced by the river's hydraulics and morphology. Without adequate sediment control, the channel may tend toward a braided condition, with an increase in divided flow reaches and a decrease in flood and navigation controls. General Ferguson's cutoff program imposed a condition on the river from which it may never recover.

The river has tried to regain its precutoff length, but the revetment and dike program, realignment dredging, and natural point bar chute cutoffs have held the river to an almost constant length in the reach of the cutoffs. Table 2 shows the thalweg length of the river from a point just above the Hardin Cutoff to a point just below Glasscock Cutoff at Washout Bayou.

Table 2

Thalweg Length of Mississippi River from Above Hardin Cutoff to Below Glasscock Cutoff

Year	Thalweg Length miles
1932	503
1944	340
1950	345
1972	346
1975	343

Since 1972, we have had three years of extremely high water. Figure 9 is a histogram of the mean daily discharge from 1817 to the present. The highest average daily flow of record occurred in 1973. This extended period of high water has shortened the river in the cutoff reach approximately 3 miles.

There is some question of the accuracy in the discharge data prior

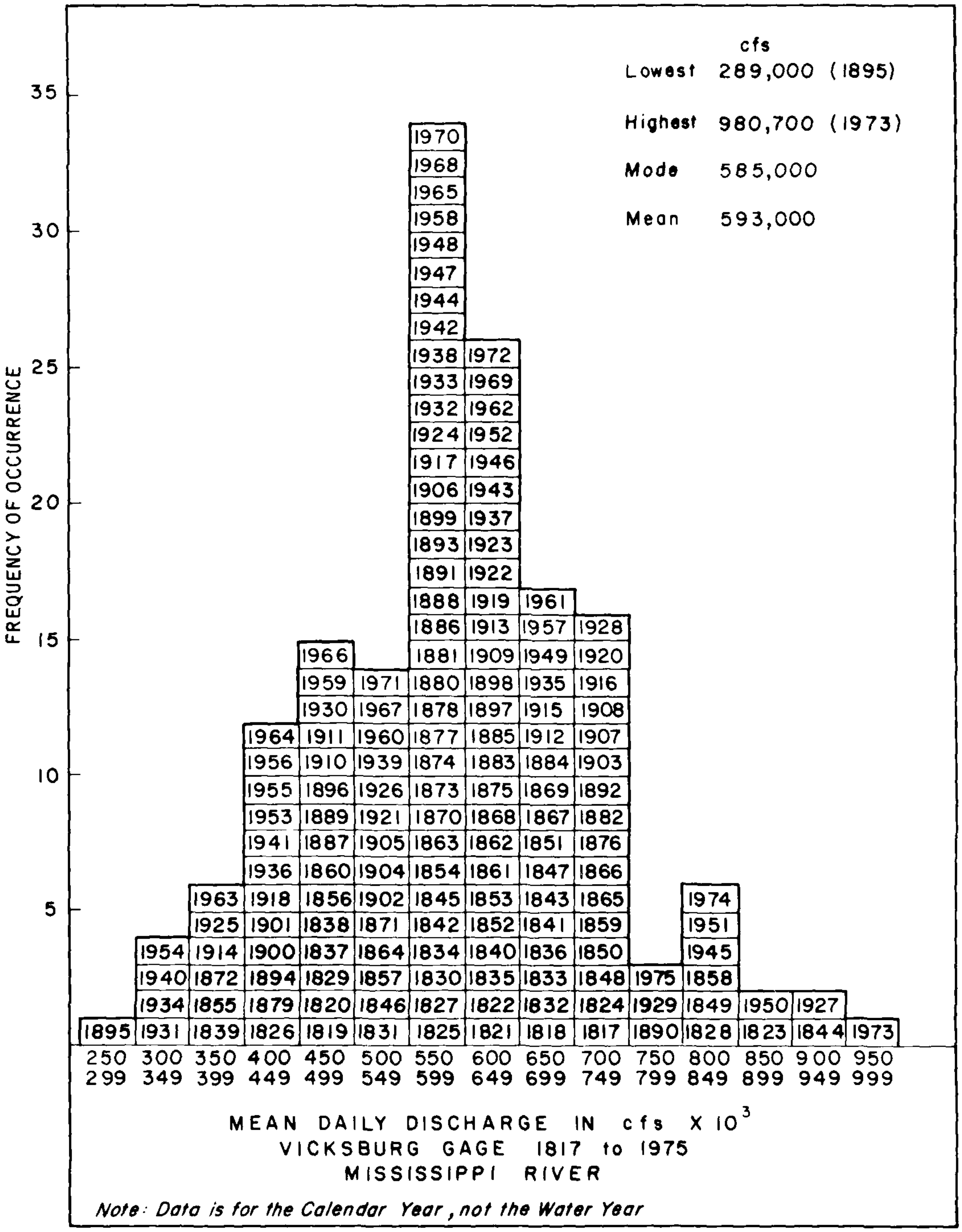

cfs
Lowest 289,000 (1895)
Highest 980,700 (1973)
Mode 585,000
Mean 593,000
FREQUENCY OF OCCURRENCE
35
30
25
20
15
10
5
1895
1931 1934 1940 1954
1839 1855 1872 1914 1925 1963
1826 1879 1894 1900 1901 1918 1936 1941 1953 1955 1956 1964
1819 1820 1829 1837 1838 1856 1860 1887 1889 1896 1910 1911 1930 1959 1966
1831 1846 1857 1864 1871 1902 1904 1905 1921 1926 1939 1960 1967 1971
1825 1827 1830 1834 1842 1845 1854 1863 1870 1873 1874 1877 1878 1880 1881 1886 1888 1891 1893 1899 1906 1917 1924 1932 1933 1938 1942 1944 1947 1948 1958 1965 1968 1970
1821 1822 1835 1840 1852 1853 1861 1862 1868 1875 1883 1885 1897 1898 1909 1913 1919 1922 1923 1937 1943 1946 1952 1962 1969 1972
1818 1832 1833 1836 1841 1843 1847 1851 1867 1869 1884 1912 1915 1935 1949 1957 1961
1817 1824 1848 1850 1859 1865 1866 1876 1882 1892 1903 1907 1908 1916 1920 1928
1890 1929 1975
1828 1849 1858 1945 1951 1974
1823 1950
1844 1927
1973
250 299
300 349
350 399
400 449
450 499
500 549
550 599
600 649
650 699
700 749
750 799
800 849
850 899
900 949
950 999
MEAN DAILY DISCHARGE IN cfs X 10³
VICKSBURG GAGE 1817 to 1975
MISSISSIPPI RIVER
Note: Data is for the Calendar Year, not the Water Year

Figure 9

to 1874. Accordingly, Figure 10 is a histogram of the more reliable record of mean daily discharges from 1874 to present. The shape of the histogram is essentially the same. Note that the nine years with average discharges over 750,000 cfs included 1973, 1974, and 1975.

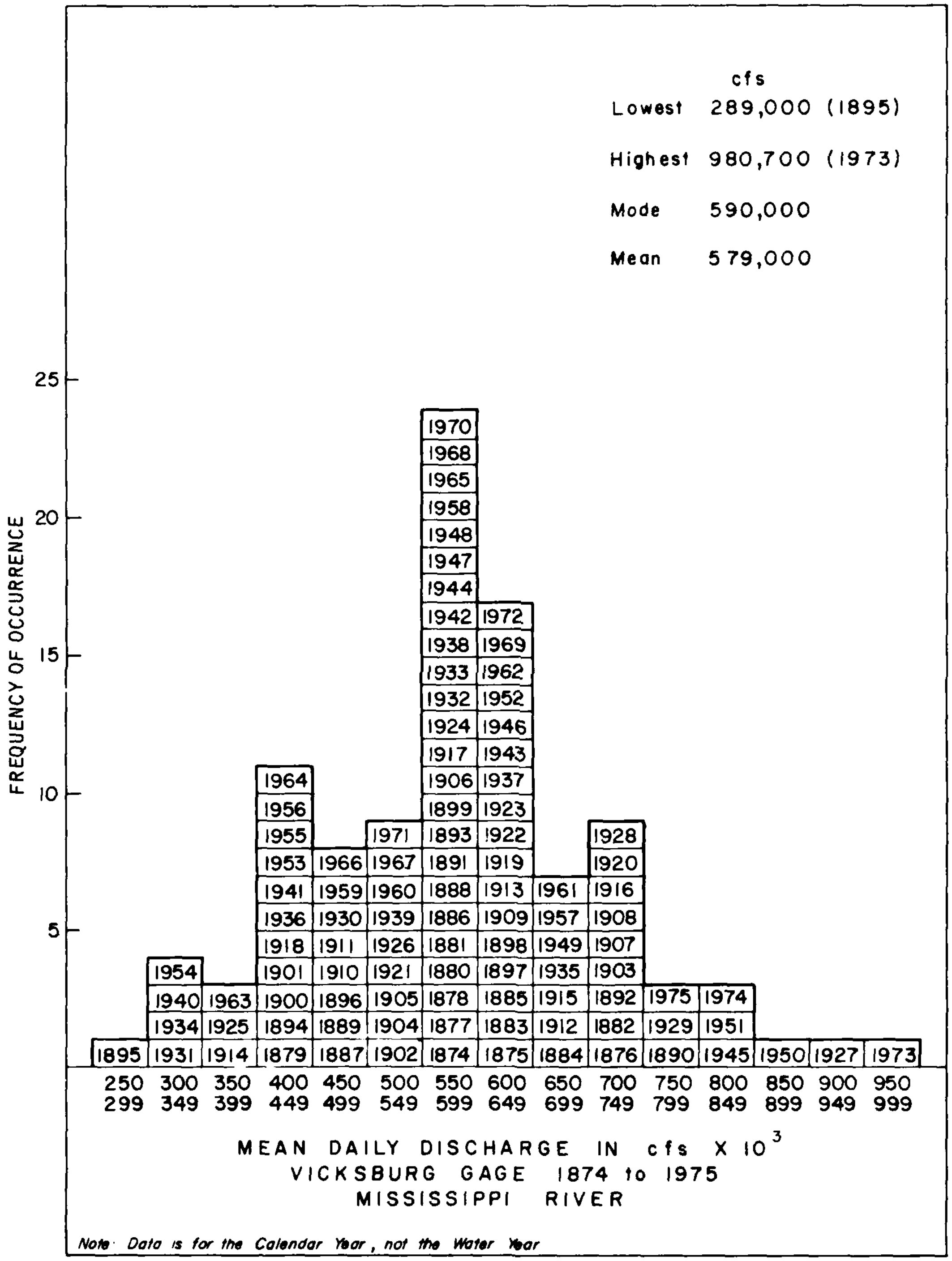
Historically, the river has adjusted its length to changes in meander belt and delta outlet (Figure 3) and thus varied about some constant length and slope for a particular set of conditions. The present river is no longer allowed to meander and has had a 50 percent flow increase caused by levees and closure of many natural outlets. In addition, the delta outlet location is now fixed, causing the lower portion of the river to develop a continually flatter slope. This has significantly upset the geometric consistency of the river and the movement of sediments through the system.

Prior to 1765 (the first map of the Lower Mississippi River), the river made about 14 natural neck cutoffs per 100 years. Table 2 lists 18 cutoffs between 1776 and 1884 or 16.7 cutoffs per 100 years. During this period, 12 chute cutoffs also occurred. In 1884, the Mississippi River Commission adopted a "cutoff prevention" plan and prevented all cutoffs until 1929 when the Yucatan Cutoff was allowed to develop. As has been stated, the "orderly" development of this cutoff convinced General Ferguson that he could shorten the river with no adverse effects. Table 3 lists the chute cutoffs that developed between 1884 and 1930.

Even with an active program of cutoff prevention, the river shortened itself over 45 miles during this period. Due to natural meandering tendencies, however, the 1930 river was actually 14.2 miles longer than the 1884 river. During this period, many methods of bank protection and river training structures were tried. Willow mats weighted with stone were the most successful.

Between 1929 and 1942, two natural neck cutoffs were allowed to develop, and 14 neck cutoffs were constructed by the Corps of Engineers (Table 4 and Figure 11). Since that time no neck cutoffs have been allowed to develop although many chute cutoffs have occurred.

During the 23-year period from 1932 to 1955, over 500,000,000 cu yd of material were dredged to develop chute cutoffs. Table 5 lists the



cfs
Lowest 289,000 (1895)
Highest 980,700 (1973)
Mode 590,000
Mean 579,000
FREQUENCY OF OCCURRENCE
MEAN DAILY DISCHARGE IN cfs X 10³
VICKSBURG GAGE 1874 to 1975
MISSISSIPPI RIVER
Note: Data is for the Calendar Year, not the Water Year

Figure 10

Table 3

Chute Cutoffs, 1884-1930

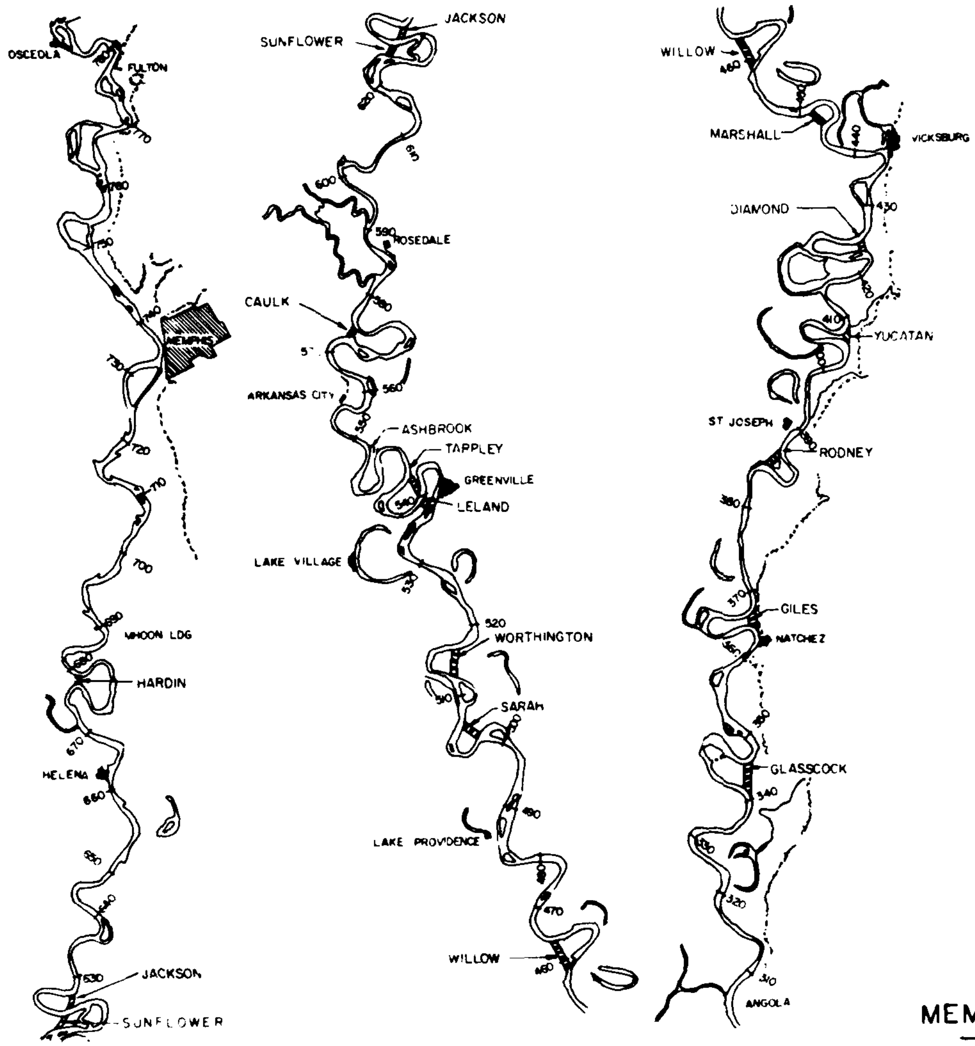
Approximate River Mile Location on 1975 Maps		Original Length of Bendway Measured Off 1975 Maps, miles	Chute Length miles	Distance River Shortened miles
930	Wolf Island	10.0	6.0	4.0
875	Tiptonville	4.1	3.3	0.8
781	Flower Island	5.6	2.6	3.0
765	Island 35	13.9	7.0	6.9
746	Islands 40-41	9.7	4.0	5.7
738	Hopefield Bend	5.3	3.7	1.6
716	Cow Island Bend	4.9	4.0	0.9
618	Island 63	5.9	4.0	1.9
606	Concordia	8.9	2.2	6.7
478	Fitler Bend	6.8	4.1	2.7
463	Newman	8.0	2.3	5.7
460	Island 102	4.2	1.3	2.9
432	Racetrack	6.1	3.7	2.4
	TOTALS	93.4	48.2	45.2

Table 4

Man-Made Neck Cutoffs, 1929-1942

River Mile Location on 1975 Maps		Year Opened	Bendway miles	Cutoff Distance miles	Distance River Shortened miles
678	Hardin	1942	18.8	1.9	16.9
628	Jackson	1941	11.1	2.4	8.7
625	Sunflower	1942	12.9	2.5	10.4
575	Caulk	1937	17.2	2.0	15.2
549	Ashbrook	1935	13.3	1.9	11.4
541	Tarpley	1935	12.2	3.6	8.6
589	Leland*	1933	11.2	1.4	9.8
514	Worthington	1933	8.1	3.8	4.3
504	Sarah	1936	8.5	3.2	5.3
463	Willow	1934	12.4	4.7	7.7
448	Marshall	1934	7.3	3.1	4.2
424	Diamond	1933	14.6	2.6	12.0
408	Yucatan*	1929	12.2	2.6	9.6
388	Rodney	1936	10.0	4.1	5.9
366	Giles	1933	14.0	2.9	11.1
343	Glasscock	1933	15.6	4.8	10.8
	TOTALS		199.4	47.5	151.9

* Natural cutoffs.



VICINITY MAP

MILEAGE SHORTENING WITH NAVIGATION THROUGH THE SIXTEEN CUT OFFS MADE SINCE 1929 INSTEAD OF AROUND THE BENDS

NAME OF CUT-OFF	YEAR OPENED	SHORTENING IN MILES
HARDIN	1942	16.9
JACKSON	194[illegible]	8.7
SUNFLOWER	1942	10.4
CAULK	1937	15.2
ASHBROOK	1935	11.4
TARPLEY	1935	8.6
LELAND	1933	9.8
WORTHINGTON	1933	4.3
SARAH	1936	5.3
WILLOW	1934	7.7
MARSHALL	1934	4.2
DIAMOND	1933	12.0
YUCATAN	1929	9.6
RODNEY	936	5.9
GILES	1933	11.1
GLASSCOCK	1933	0.8
TOTAL SHORTENING AT THE CUT OFFS		[illegible]

BENDS SHOW CONDITIONS WHEN CUT OFFS WERE MADE

LEGEND

530 MILES ABOVE HEAD OF PASSES (1962)

SCALE IN MILES
5 0 5 10

CUTOFFS
BETWEEN
MEMPHIS TENN. & ANGOLA, LA.

Figure 11

Table 5

Chutes Developed Since 1939

	Approximate River Mile Location on 1975 Maps	Distance River Shortened miles	1975 River in New Alignment Yes	No	Remarks
942	Islands 3 and 4	3.3	X		
933	Wolf Island	(0.7)*		X	Bendway developed
922	Island 6	1.0	X		
915	Island 8	3.4	X		
900	Island 10	1.4	X		
887	New Madrid Bend	1.1	X		
882	Toney's Chute	(0.8)		X	Bendway developed
872	Merriwether Bend	1.2		X	River migrated
865	Little Cypress Bend	2.0	X		
858	Chute of Island 14	2.8	X		
850	Little Prairie Bend	1.7	X		
848	Blaker Towhead	1.0	X		
835	Island 18	0.5	X		
798	Forked Deer Island	3.2	X		
787	Island 30	1.3		X	River migrated
780	Driver Cutoff	3.8	X		
775	Island 34	2.6	X		
765	Island 35	4.2	X		
752	Brandywine Chute	6.5	X		
740	Memphis Reach	(0.2)	X		Forced alignment
	Subtotal	39.3			
(648	Hardin Cutoff - Farthest upstream of man-made cutoffs)				
667	Flower Lake Bar	1.0	X		
656	Montezuma Bend	0.7	X		
647	Island 61	0.7	X		
638	Island 63	(1.1)		X	River migrated
616	Cessions	0.7	X		
613	Island 69	0.0	X		Channel adapted to upstream conditions
585	Rosedale Bend	1.4		X	River migrated
533	Walker Bend	1.3	X		
527	Lakeport Towhead	0.8	X		
517	Kentucky Bar	(0.6)		X	Reverted to bendway
510	Cracraft Chute	1.5	X		

(Continued)

* Numbers in parentheses indicate that 1975 river is longer than the earlier river.

Table 5 (Concluded)

Approximate River Mile Location on 1975 Maps		Distance River Shortened miles	1975 River in New Alignment Yes	No	Remarks
502	Opossum Chute	2.5	X		
470	Cottonwood	2.7	X		
430	Racetrack	2.1	X		
415	Togo	2.3	X		
409	Middleground	(1.6)		X	River migrated
402	Coffee Point	(0.5)		X	River migrated
392	Bondurant	(0.3)		X	Reverted to bendway
377	Waterproof	(0.2)	X		River migrated
357	Natchez Island	1.3		X	River migrated
	Subtotal	14.7		X	River migrated
(353 Glasscock Cutoff - Farthest downstream of man-made cutoffs)					
	Miles shortened	54.0			

40 chutes that were developed with the thought of giving the river a better alignment, improving navigation, and attempting to more closely align the high- and the low-water flow paths. Also, it was thought that the latter would minimize bank caving. No distinction has been made in the table between those that developed naturally and those that were man-made.

Attempts were made to develop more chutes, but for a variety of reasons the river would not cooperate and the efforts were finally abandoned. Many of these chute cutoff locations are divided flow reaches today and present both navigation and flood control problems. The above-mentioned 40 chute cutoffs have almost balanced the river's attempts to regain its length. There is only a 3-mile difference (Table 2) in the 1975 and 1944 lengths in the reach of cutoffs; however, twenty of the above-mentioned chute cutoffs were upstream of Hardin Cutoff.

6.01 Description of Each Cutoff Development. Literary reports of the cutoffs seem to present a very favorable picture. Initially this was true; however, the ultimate long-range responses present a less favorable picture. Very little data were found in files on the

construction of each cutoff, and still less on the response of the overall river or its reaction to each cutoff. In order to present as factual a picture as possible and to present all available data, the two most accepted writers, R. K. Stewart of the Vicksburg District and G. R. Clemens of the Mississippi River Commission, are quoted. The role of development dredging in support of the chute cutoff program can be seen from a summary of construction efforts at Opossum and Cracraft chutes.

No design memorandum or evidence of precutoff engineering could be found in the records of either Vicksburg District or Mississippi River Commission. The following statement by G. H. Matthes[7] seems to be the only precutoff design criteria:

> After selecting the alignment for the cutoff pilot channel, the right-of-way is cleared for 1000 ft; being 500 ft on each side of the center line of the cut. Of this, the central 500 ft is grubbed. After the clearing and grubbing is completed, the pilot channel is excavated by dredges to a bottom width of 250 ft at a grade line from 10 to 20 ft below the water surface at extremely low water, depending upon the character of the soil along the cut. To ensure the development of the pilot channel, care is taken to carry the bottom grade of the cut to below any clay deposits into the erodible sands of the Mississippi River floodplain. The material from the cut is generally placed in the river channel immediately below (downstream) the head and foot of the cutoff Pilot Channel.

As noted in Section 4, General Brown and General Ferguson began studying the feasibility of cutoffs in 1929 while the latter was stationed elsewhere. As far as today's records reveal, little engineering design work was done, and only a few soil borings were taken prior to construction of most of the cutoffs. Ferguson's generalized plan included the development of cutoffs, corrective dredging in reaches between cutoffs, and rectification of the channel at other selected points.

The objective of the plan was to direct the river's energy in the improvement of the channel so that floods could be carried at lower stages. This was to be accomplished by:

- a. Reducing excessive curvature and correcting the alignment.
- b. Shortening.

c. Reducing the number of crossovers.

d. Enlarging primary channels.

e. Closing off secondary channels.

f. Controlling the erosion of bars and banks.

g. Deepening channels.

h. Enlarging cross-sectional areas.

i. Removing obstructions and constrictions.

A comparison of hydraulic and geometric variables (Sections 8 and 9) will help to portray the river's actual response to these measures.

Because no complete report was ever compiled on all of the cutoffs, the data recorded on each vary widely in detail and in quantity of documentation. The following descriptive paragraphs on the cutoffs were gleaned from the MRC files.

In an in-house report on the cutoffs between Yucatan and the Arkansas River, R. E. Stewart[11] states:

> The period covered (1932-42) is from the inception of the new program (on cutoffs) through the first 10 years of its construction, operation, and maintenance. The purpose of this history is to put on paper the ideas, causes, some of the theory, methods, mistakes, and results attained in order that those engaged on this, or similar work, in the future may have the advantage - or disadvantage - of the experience which we, who have followed the program through, have had. It is hoped thereby to enable those future workers in the crusade against floods to at least keep from making some of the mistakes we made.

Each cutoff will be discussed in turn starting upstream at Hardin and continuing downstream to Glasscock (Figure 11). Comments by Stewart[11] and/or Clemens[14] are included with each cutoff, as well as available pictures amd maps of the river's development.

6.02 Cracraft Chute. Several point bar chutes were developed during the decades following the cutoff. Some have remained active; however, others reverted to the original channel in spite of repeated dredging in an attempt to maintain them.

Cracraft Chute connected Worthington and Sarah Cutoffs (Figure 11).

It was a cutoff but was never considered as such because it was a point bar chute rather than a neck cutoff. The chute was 4.6 miles long and the bendway 6.8 miles, making the slope only 1.47 times as great through the chute. It required an extreme amount of dredging to develop the channel for navigation (Table 6). More corrective dredging was done on this chute cutoff than any of the neck cutoffs except Glasscock.

Table 6

Dredging Required to Develop Cracraft Chute

Year	Amount Dredged cu yd	Dredged Accumulation cu yd
1934	5,155,014	
1935	6,325,980	11,480,994
1936	2,018,494	13,499,488
1937	4,446,705	17,946,193
1942	9,305,198	27,251,391

Concerning the Cracraft Chute, Stewart comments:

> Immediately downstream from Worthington Cutoff, a divided channel existed. The Island between the two channels was Cracraft Towhead. The channel to the right of the towhead is Cracraft Chute and for many years had been the secondary channel except at high river stages when, due to its wide, shallow cross section, its discharge became approximately the same as that passing to the left of the island.... In view of its shorter length, the chute should have been the main channel through natural action. Therefore, there must be some unusual reason for its failure to improve. It was found that this reason was the heavy deposits of gravel at the upstream end. As a part of the general program, which required the decrease in length of the river, it was essential that Cracraft Chute be made the main river channel. Worthington Cutoff had been started and its lower end about met the upstream end of the Cracraft Chute. Another cutoff was proposed at Sarah Island, which was immediately below the downstream end of the chute. So it may be seen that Cracraft Chute was an important section of the new alignment....
>
> Operations toward the development of Cracraft Chute were begun in 1934, with dredging in the extreme

upstream end to remove gravel. Larger scale operations were carried on in 1935 when dredges made long cuts through the gravel deposit at the upper end and a shorter cut at the lower end. The cuts made at the upstream end were solely to remove gravel. It was felt that after its removal natural development would proceed apace. Then, as Worthington Cutoff improved, it was felt that it was best not to await natural development of the chute, and that large-scale dredging operations should be undertaken to expedite the improvement. In 1936, dredging was done from one end of Cracraft Chute to the other. After the spring of 1937, surveys indicated that the upstream end of the chute was improving satisfactorily but that further work in the lower end was required. These surveys also indicated that rapid deterioration was taking place in the old bend channel, which was a condition much to be desired. In the meantime, Sarah Island Cutoff had been opened immediately below Cracraft Chute, and the dredging in the lower end of the chute in 1937 was laid out to afford the most direct route into this cutoff. By the end of 1938, Cracraft Chute was definitely the Mississippi River and the old river around Princeton Bend was closed off up to about one-third bank-full stage.

6.03 Opossum Chute. Like Cracraft Chute, this cutoff was originally considered as an "improvement" in alignment (see paragraph 6.11). The chute was 4.1 miles long and 6.8 miles around the bend, making the initial slope 1.66 times greater through the cut than around the bend. The slight increase of slope coupled with the three continuous cutoffs just upstream, plus the extensive natural shortening of this reach during the past 600 years, probably accounted for the continual maintenance problem in the reach that persisted until sinuosity was gained through proper placement of dikes.

Stewart describes the chute development as follows:

> The upstream end of Opossum Chute is at the downstream end of Sarah Island Cutoff. The channel here was divided. Duncansby Towhead was the island between the divided channels. The main river channel passed to the left of Duncansby Towhead around Valewood Bend and carried practically the entire river discharge except at high stages. The channel to the right of Duncansby Towhead was Opossum Chute. It was far less efficient.... Development of the Opossum Chute channel was highly important due to its being a link in the

realignment chain made up of Worthington Cutoff, Cracraft Chute, Sarah Island Cutoff and Opossum Chute. Several miles were to be gained by this realignment.

The upper section of Opossum Chute was heavily filled with gravel, and the first work toward its development was dredging in the upstream end to open the channel through the gravel [Table 7]. Operations continued in 1936 and 1937 largely in the upstream end through the gravel deposit. It was felt that with an adequate opening through this obstructing material, the remainder of the chute would develop naturally. Subsequent observation indicated that this was not entirely true. The shoal sections at the extreme lower end did not scour; therefore, dredging was performed there to provide a suitable outlet. This constitutes another item added to our education of this period -- that no matter how adequate the upstream end of a reach may be, it cannot fully develop throughout its length without the downstream end being of sufficient capacity. Due to Opossum Chute being so greatly deficient in cross section area, much dredging was carried on at various times from one end to the other to provide much needed increase. As this work progressed, marked deterioration of the Valewood Bend channel was taking place, and by 1938 its low water depth was not even sufficient for navigation.

Table 7

Dredging Required to Develop Opossum Chute

Year	Amount Dredged cu yd	Dredged Accumulation cu yd
1934	696,000	
1935	1,750,453	2,446,453
1936	3,366,040	5,812,493
1937	23,500	5,835,993

6.04 Hardin Point Cutoff. This was the last man-made cutoff and was completed during World II. The length of the cut was only 5900 ft, and the distance around the bend was 18.82 miles, making an initial slope across the cut 16.84 times that around the bendway. Construction began in January 1942 and was completed in March 1942, after about

3,000,000 cu yd of material had been excavated by dredging a 200 ft wide to -15 ft mean low water (mlw) pilot cut. A plug left in the pilot cut was breached by dynamiting 18 March 1942, with the river stage near midbank. The cutoff developed rapidly without additional dredging. By July, at a midbank river stage, the cutoff was carrying about 80 percent of the total riverflow, and by October, practically all of the low-water flow was passing through the cutoff.

When the river fell to lower stages, upstream navigation was blocked for 10 days due to swift currents at Whiskey Chute Crossing, some 4 miles above the cutoff. A federal government towboat was stationed at this location for 30 days to help navigation through the swift water. However, river traffic was navigating the cutoff with little or no difficulty by July.

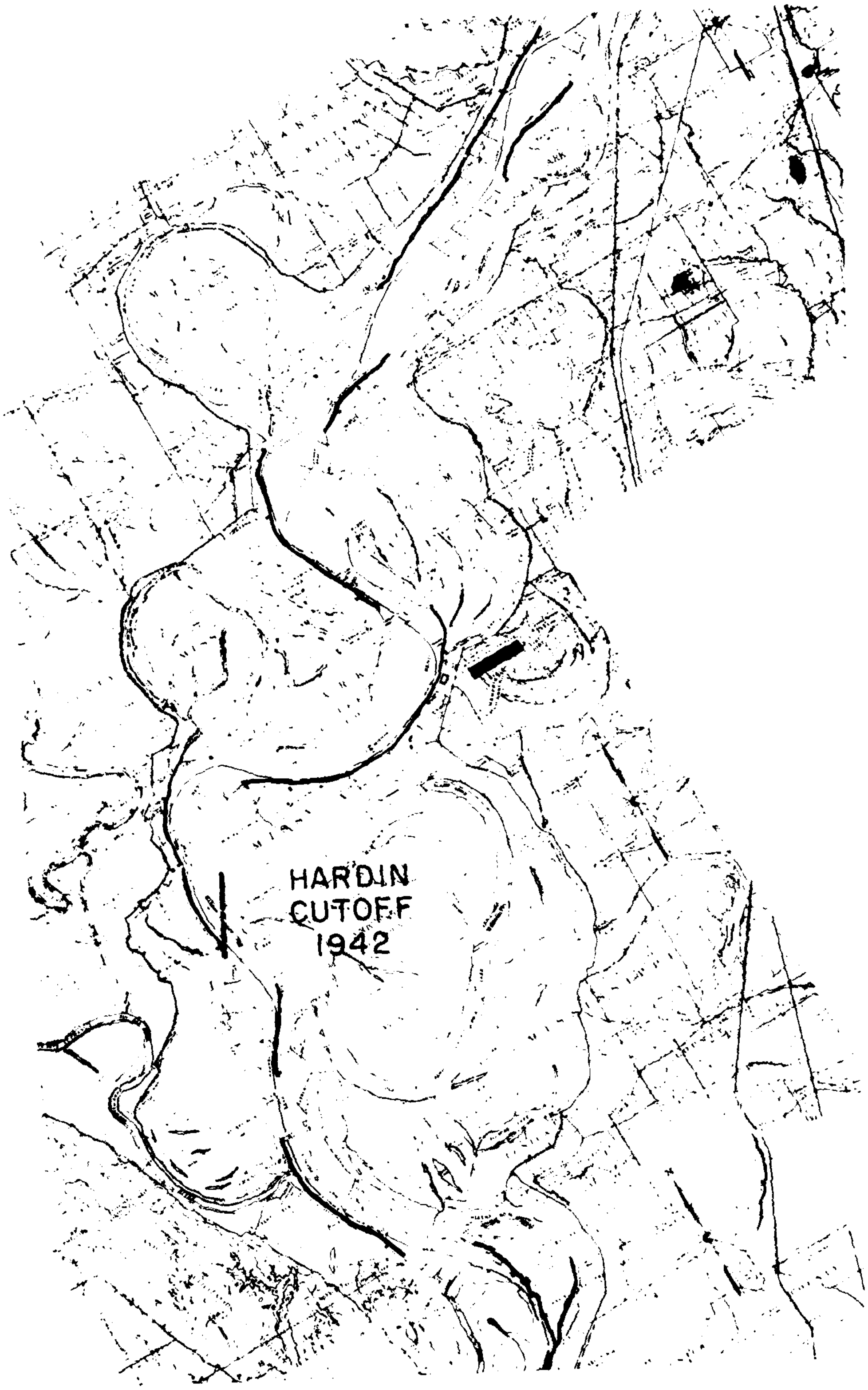
Plans for developing the cutoff included supplementary dredging along Bordeaux Point to create a channel across the point bar, thus alleviating the scouring attack against the critical area at Walnut Bend. In April 1942, when prevailing current velocities were too great for dredging operations, dredging at Bordeaux Point was abandoned and the pointway channel was never developed.

Increased current velocities above the cutoff resulted in accelerated bank caving at Mhoon Bend and Walnut Bend. The condition became so critical that a levee setback and revetment were constructed at Walnut Bend under emergency conditions. These emergency works were required to prevent the Mississippi River breaching the levee and spilling into the St. Francis River. A levee setback was also necessary at Peters. The effect upon stabilization works is best illustrated by the total expenditure on the Walnut Bend revetment, immediately upstream from the cutoff, of approximately $4,410,000 in the 10 years after the cutoff was opened. The channel above the cutoff tended to become braided and develop bifurcated flow immediately after the cutoff was opened.

Figure 12 shows several surveys of the historic river in the vicinity of Hardin Point Cutoff superimposed. Figure 13 presents today's river with the revetment and dike construction. Historically, the river

HISTORIC DEVELOPMENT OF THE HARDIN POINT REACH

Figure 12



1975 MISSISSIPPI RIVER IN THE HARDIN POINT REACH Figure 13

had done an extreme amount of meandering in this reach, and natural occurrence of this cutoff would have been difficult to prevent.

6.05 Jackson Point and Sunflower Cutoffs. These two adjoining cutoffs shortened the river channel 19.1 miles. The lengths of dredge cuts for the two cutoffs were 11,300 and 10,300 ft, respectively. The depths of pilot cuts were -15 and -20 ft mlw. Plans called for a simultaneous opening of the cutoffs at a high river stage. However, the plug in the dredged pilot cut of Jackson Point Cutoff failed, causing this cutoff to open first on 26 April 1941. Sunflower Cutoff was opened approximately one year later on 16 February 1942.

The length of the Jackson cut was 11,300 ft, and the distance around the bend was 11.06 miles, making the slope across the cut 5.17 times greater than the bendway. No additional dredging is recorded in the original cut.

The length of the Sunflower cut was 10,300 ft, and the distance around the bend was 12.87 miles, making the slope across the cut 6.60 times greater than the bendway. Only 668,446 cu yd of additional dredging in 1942 is recorded.

The Jackson Point Cutoff developed rapidly and was carrying over 50 percent of the low-water flow by July 1941 and over 90 percent by September 1942. Sunflower Cutoff required additional dredging at the lower end of the pilot cut to hasten its natural development. Over 70 percent of the low-water flow was passing through Sunflower Cutoff by September 1942, and by July 1943, the cutoff was carrying practically all of the low-water flow.

The two cutoffs increased bank caving both upstream and downstream. A setback levee and emergency revetment operations were required at Fair Landing. Accelerated bank caving also increased the requirement for revetment at other locations. Navigation difficulties were encountered at Fair Landing, Old Town, and Helena because of increased current velocities. The dredging requirements in the difficult Island 63 Reach, 10 miles upstream, were increased.

Jackson and Sunflower Cutoffs shortened an extremely sinuous river length of 24 miles to only 4 miles. A major effort of dike and

revetment construction has been required to maintain the navigation channels. Figure 14 shows the historic development, and Figure 15 the present river in this reach with the location of dikes and revetment constructed through 1975.

These three cutoffs (Hardin, Jackson, and Sunflower) were all made several years after the original cutoff program and above the confluence of the White River. The slope differential is very high for each of these cutoffs, and it is inferred herein that they developed without much additional work. It should be noted though that an extreme amount of maintenance dredging has been required in that reach of river.

The length of the river from above Hardin to just below Sunflower Cutoff is about 55 miles today. Historically, this reach of river averaged 93 miles. The extreme slope change resulting from this shortening is partially responsible for instability and extra maintenance dredging required in the reach.

6.06 Caulk Neck Cutoff. The original length of cut was 4500 ft between top banks, and the distance around the bend was 17.2 miles giving a slope increase across the neck 20.5 times greater than around the bend. The cutoff developed very rapidly.

Stewart describes the development as follows:

> This was the last cutoff made in the Vicksburg District to the present time; there is not another long meander left that offers promise as a suitable or advantageous location for further shortening. Caulk Neck was the longest one of all. The length of river around it from one end of the cutoff to the other was 17.2 miles. Caulk Neck is about 6 miles below the mouth of Arkansas River. This neck, like so many of the others, had been protected with revetment at what appeared to be its weakest point in order to prevent a cutoff, but with river shortening being the keynote of the times, it was inevitable that one should be made here. The other cutoffs had been open for one to four years, and there had been ample opportunity for observing their action and results. None of them had given any increase in gage heights below, and obviously could not do so above, so no one was fearful of the results even though 15.2 miles were to be dispensed with....

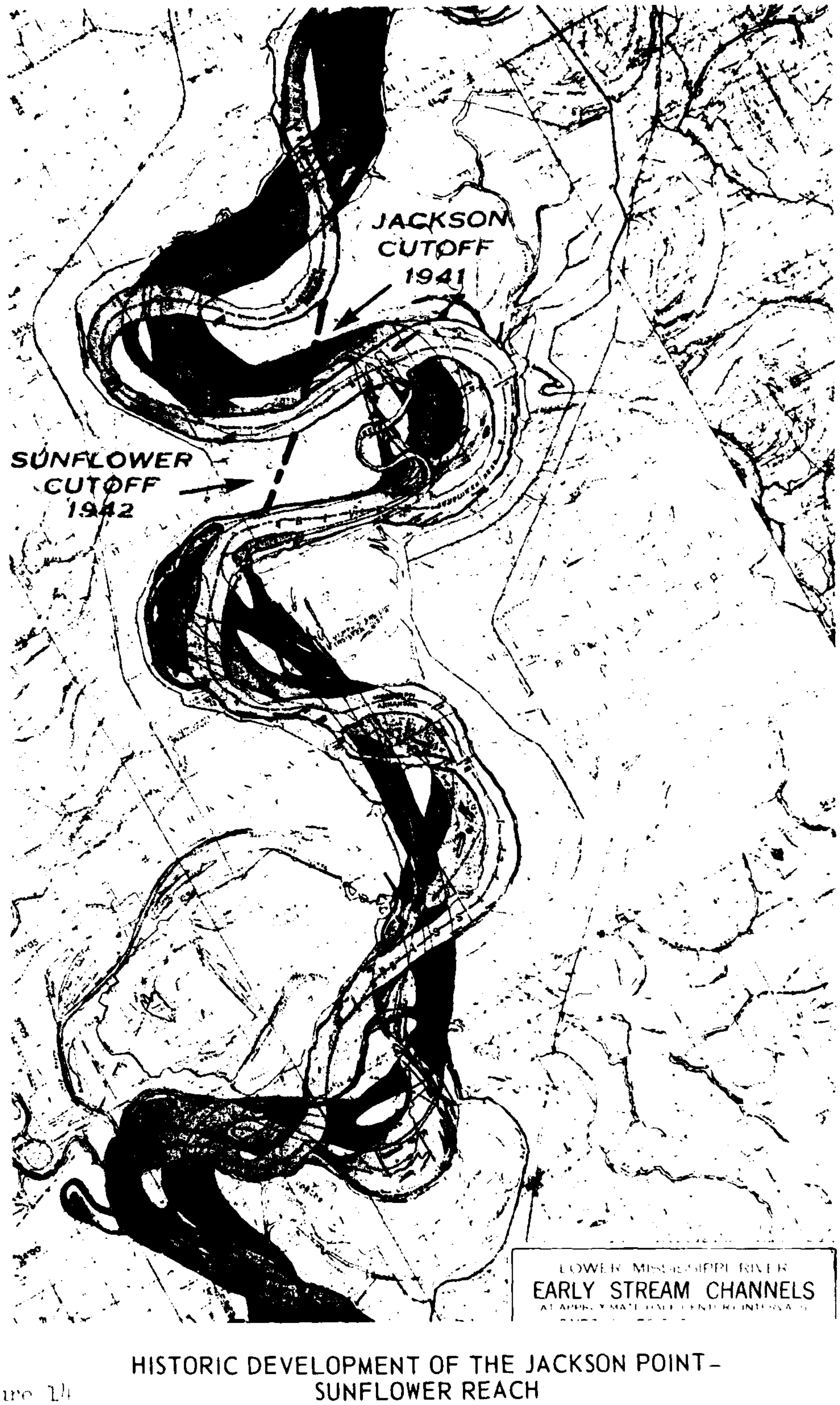
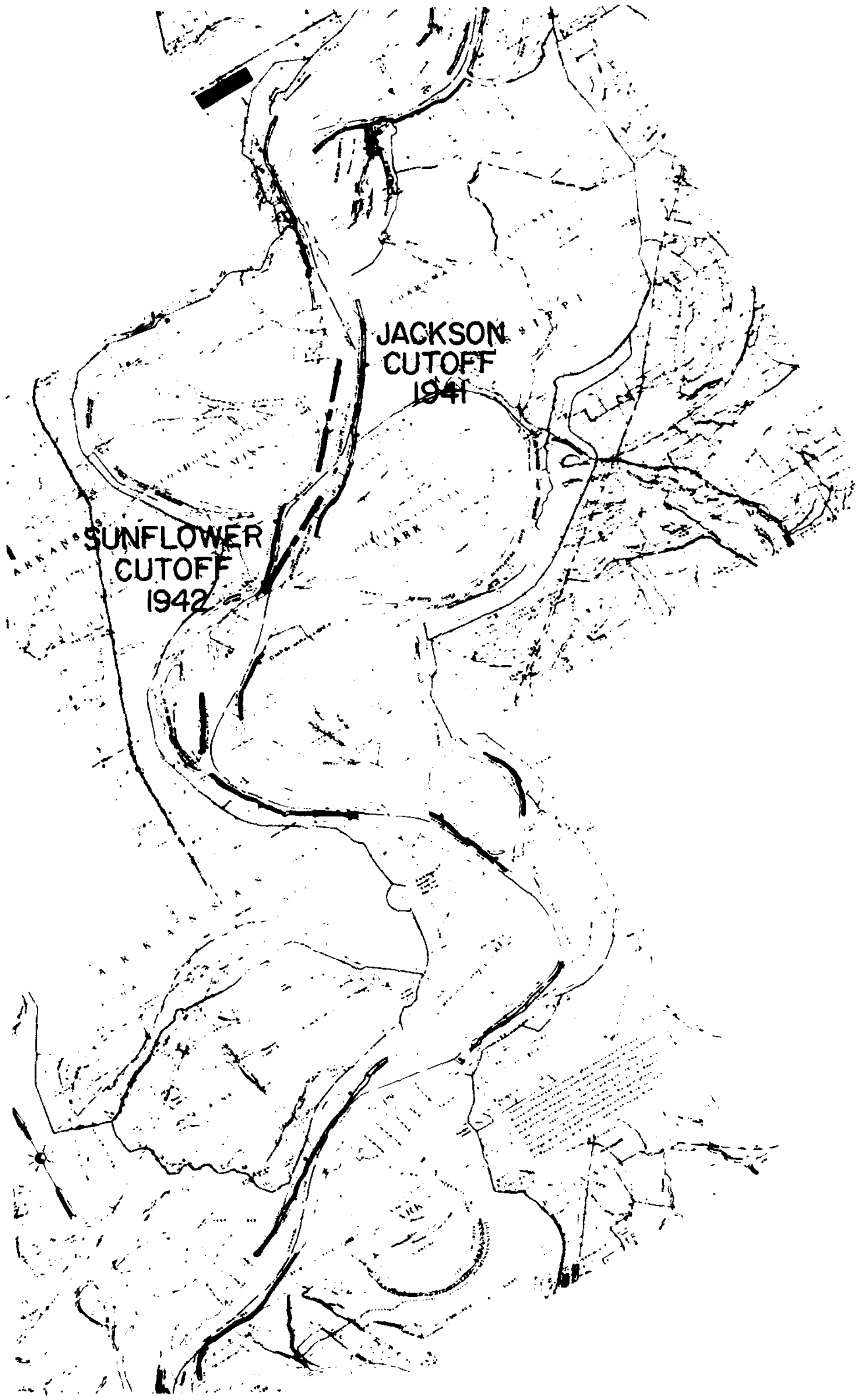


Figure 14

HISTORIC DEVELOPMENT OF THE JACKSON POINT-
SUNFLOWER REACH



1975 MISSISSIPPI RIVER IN THE JACKSON POINT-SUNFLOWER REACH

Figure 15

The plan of operation was to excavate the main section of the neck with large cutterhead dredges and to make a cut across the sand bar with a small dragline merely to lead flow across the bar on the desired line. The ditch in the sand would take care of itself when the main neck was opened.

Work started in the spring of 1937, with dredges working at either end of the cut. During the period of construction, the river stage remained around half bank-full. It was planned for the two dredges to work toward the middle of the neck leaving a narrow plug there to be blasted out.

We let our enthusiasm overweigh our good judgement in deciding on the depth of cut. The great amount of shortening and the considerable drop in water-surface elevation from above to below the neck led to the belief that almost any kind of opening, made across the neck would enlarge rapidly.... In the upper end of the cut, stiff clay material and buried cypress stumps were encountered near the bottom of the cut. We should have known by now that such material cannot be moved by river current unless the clay is dug through to the underlying sand, then it will be undermined and will break off as the sand washes from under it. When the cuts advanced until about 600 ft of high bank separated them, the dredging was stopped. A narrow, shallow opening was made through this 600 ft by the dragline. The intent was that this small dragline cut would be in sand and that no more dredging was necessary. The depth of the dragline cut was below the water surface of the cut above. A small plug was left between the upper cut and the dragline cut. Many spectators were present when this plug was blasted out. The water rushed through until the sand was scoured away and there remained stiff, nonerodible clay and stumps. Consternation and surprise were great when it was realized that the clay would not give way even with the great head in the cut. It was evident then that the only thing to do was start at the upper end with another dredge cut, making it deep enough to get below the clay. It was noted that the lower section, which had been in sand all the way, gave promise of developing without further help. The dredge made a cut from the upper end all the way through the clay section. The bottom depth this time was to not less than 10 ft below standard low water and was kept below the clay deposit. This time a real cutoff was made. It would now carry the water,

> but our worries were not yet over. So much water went through the cutoff that the old bend channel filled rapidly. Soon all navigation had to pass through the new channel. It was narrow and the current was swift. The clay refused to let the cut widen. Strong eddies were caused by jutting points at the upper end on the right bank. It was obvious that the cut had to be widened at the upper end for the benefit of navigation. Remember that navigation is as important as flood control on the Mississippi River. The widening was accomplished by blasting and dredging on the right bank at the upper end. When this was finished, there were no more troubles with Caulk Neck Cutoff.
>
> Marked change took place in the river for several miles above the cutoff. The "draw down" was considerable. Whereas the (prior) river from Caulk Neck upstream to above Rosedale, Mississippi, wandered somewhat at will between the main banks, particularly at low water, it was now pulled to a fairly uniform course. Low-water navigation difficulties in the reach were ended....

The timing of construction of this cutoff differed from those previously made in that it was opened at the beginning of the low-water season rather than at the end of the season or beginning of the high-water season. Nevertheless, it developed quite rapidly except for the upstream entrance where periodic additional dredging and blasting efforts were required to keep pace with the development of the remainder of the cutoff. Dredging in the old Bolivar Bend channel was required in 1937 to maintain navigation while the cutoff was developing. Subsequently, difficulties developed in the 40 miles of river upstream of Caulk Neck Cutoff.

Today's river in this reach (Caulk Cutoff) is one of the most stable in the entire cutoff reach, partly because the extreme degradation from the Greenville Cutoff just downstream has worked its way through the Caulk Neck Reach, partly because of a high (42 percent) silt-clay in the banks, and partly because the banks were revetted in a sinuous path with well-controlled crossings. Table 8 gives pertinent data on the Caulk Neck development.

Table 8

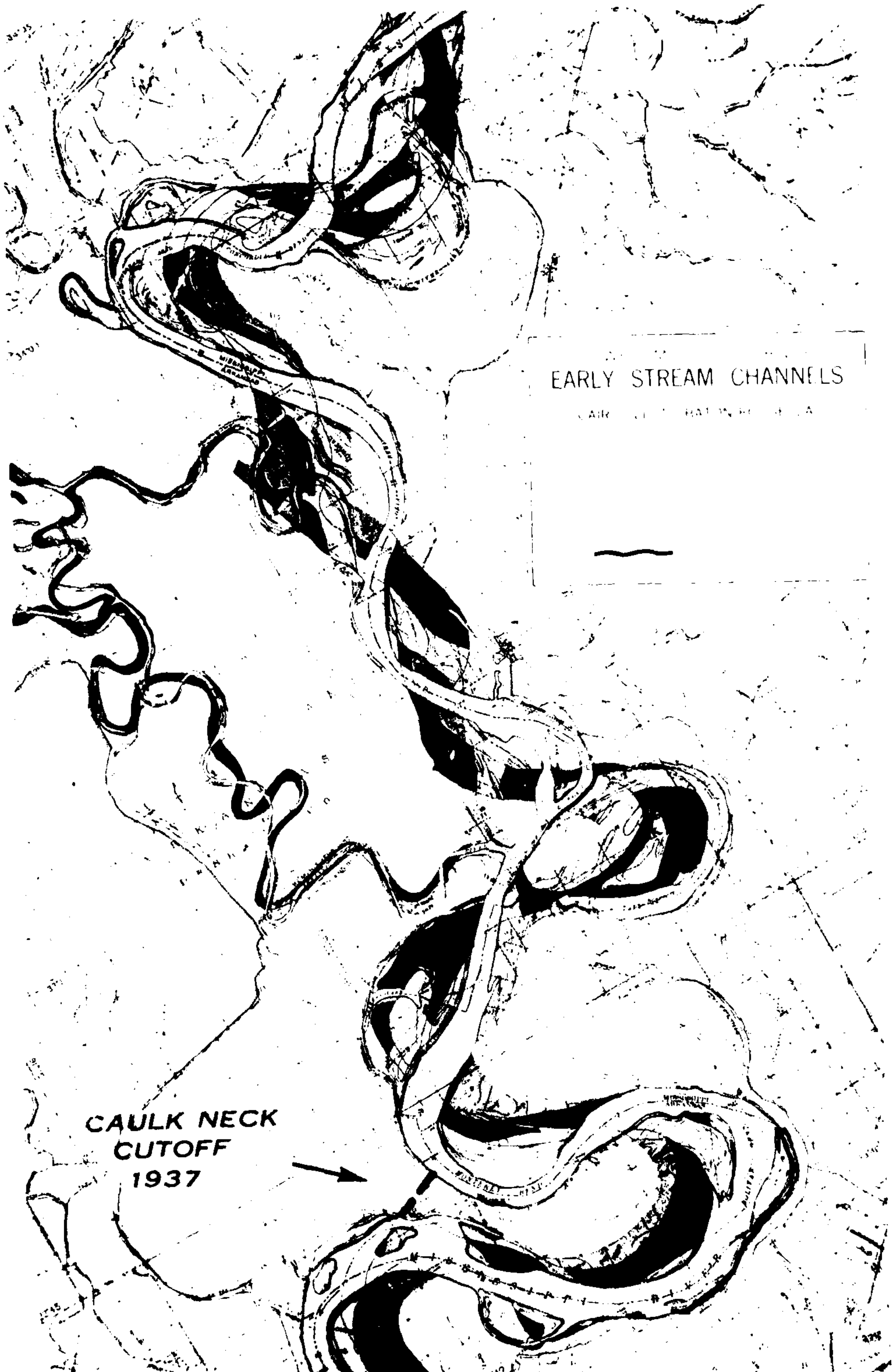
Caulk Neck Cutoff Development

Date	Arkansas City Gage, ft	Flow in Cutoff % Low Water	Average	High Water	Amount Dredged cu yd	Dredged Accumulation cu yd
Initial cut opened 5/13/37					2,411,160	
5/22/37	36.3			1		
7/7/37	20.1		13			
8/3/37	9.7	27				
11/10/37	10.0	58				
12/18/37	0.1	82				
12/31/37	19.2		56			
1938	8.0	100			2,344,000	4,755,160
Opened for navigation 6/10/38						
1939				87	127,910	4,883,070

Figures 16 and 17, respectively, show the historic river and the present river in the Caulk Cutoff Reach. Figure 18 presents four aerial photographs (1937-74) of the cutoff. This reach of river below the confluence of the Arkarsas and White Rivers has historically been very sinuous.

6.07 Greenville Reach. Since the earliest days of settlement in the valley, the reach of river from Arkansas City, Arkansas, to Greenville, Mississippi, had been noted for its extreme sinuousity containing five great bends in a river distance of 47 miles. Much effort and money had been expended on preventing natural cutoffs across the necks between bendways. Revetments and dikes had been constructed in an effort to prevent cutoffs at any price. Figure 19 is a copy of a telegram revealing the concern for preventing cutoffs in 1932.

Figure 20 is a comparison of the Greenville Reach in 1933 with 1975. The structures built in an effort to prevent cutoffs prior to 1932 are shown as well as the structures built recently in an effort to hold the channel in its alignment after cutoffs. The flow in each survey is at a 12-ft stage, which is roughly a 25 percent bank-full flow. The 1975 river is much wider than the 1933 river but is reforming the same sequence and number of pools, bars, and crossings as existed in the 1933 survey.



HISTORIC DEVELOPMENT OF THE CAULK NECK REACH

Figure 1

1975 MISSISSIPPI RIVER IN THE CAULK NECK REACH

Figure 17

AERIAL VIEWS OF CAULK NECK CUTOFF

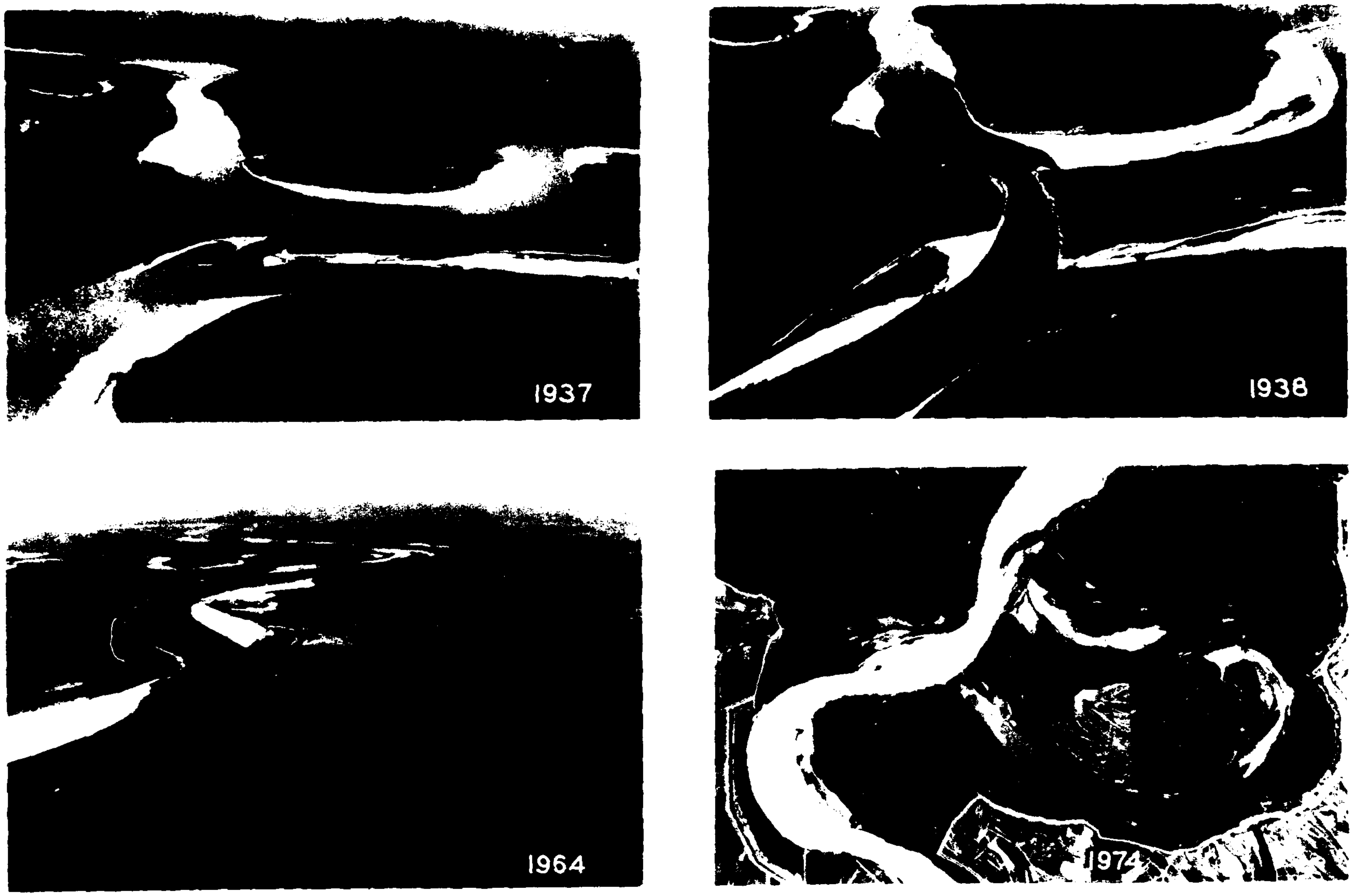


Figure 1

RECEIVED BY PRIVATE WIRE FROM
POSTAL TELEGRAPH
&
STANDARD TIME INDICATED IN THIS MESSAGE

Postal Telegraph

THE INTERNATIONAL SYSTEM

Commercial Cables — All America Cables — Mackay Radio

TELEGRAMS — CABLEGRAMS — RADIOGRAMS

This is a full rate Telegram or Cablegram unless otherwise indicated by signal in the check or in the address

DL	DAY LETTER
NL	NIGHT LETTER
NM	NIGHT MESSAGE
LCO	DEFERRED CABLE
NLT	NIGHT CABLE LETTER
WLT	WEEK END CABLE LETTER

Form 16 P. W.

P 3043/34/2

2 MH R 28 DL GOVT COLLECT 1 EX

FT MCPHEARSON GA 1046 AM JAN 23 1932

GENERAL JACKSON

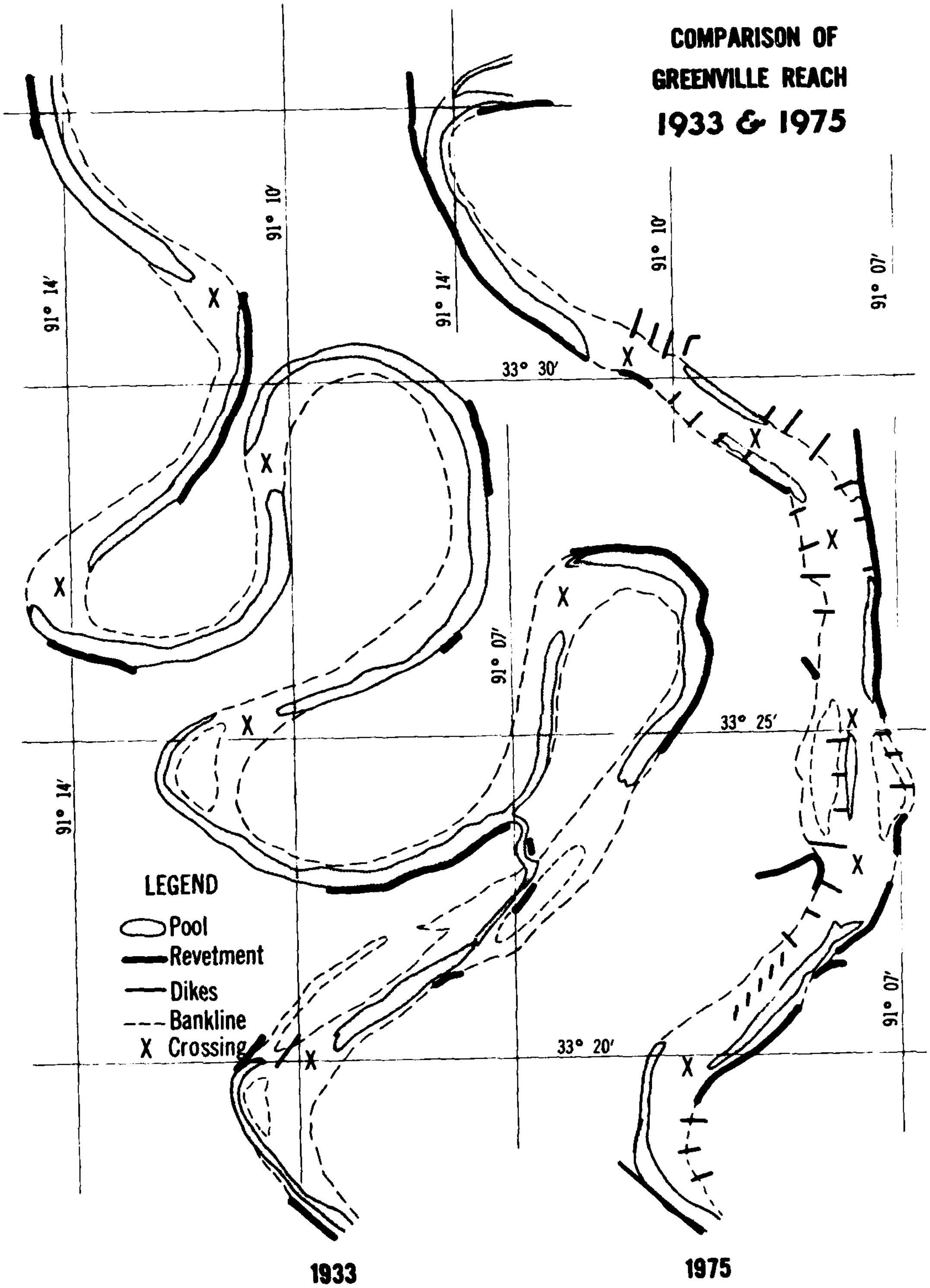
VICKSBURG MISS

KEEP TARPLEY NECK UNDER CONSTANT OBSERVATION AND IF A CUT OFF IS THREATENED MAKE PROMPT RECOMMENDATION AS TO WHAT SHOULD BE DONE TO PREVENT CUT OFF

BROWN

WASHINGTON 1111 AM

Figure 19



COMPARISON OF
GREENVILLE REACH
1933 & 1975
91° 14'
91° 10'
91° 07'
33° 30'
33° 25'
33° 20'
LEGEND
Pool
Revetment
Dikes
Bankline
X Crossing
1933
1975

Figure 20

Originally, General Ferguson[3] planned only two cutoffs in the Greenville Reach, but a natural cutoff at Leland Neck (Figure 21) forced a last minute alteration of plans. Matthes[7] states in a communication to W. E. Elam[6] of Greenville, Mississippi, in September 1940:

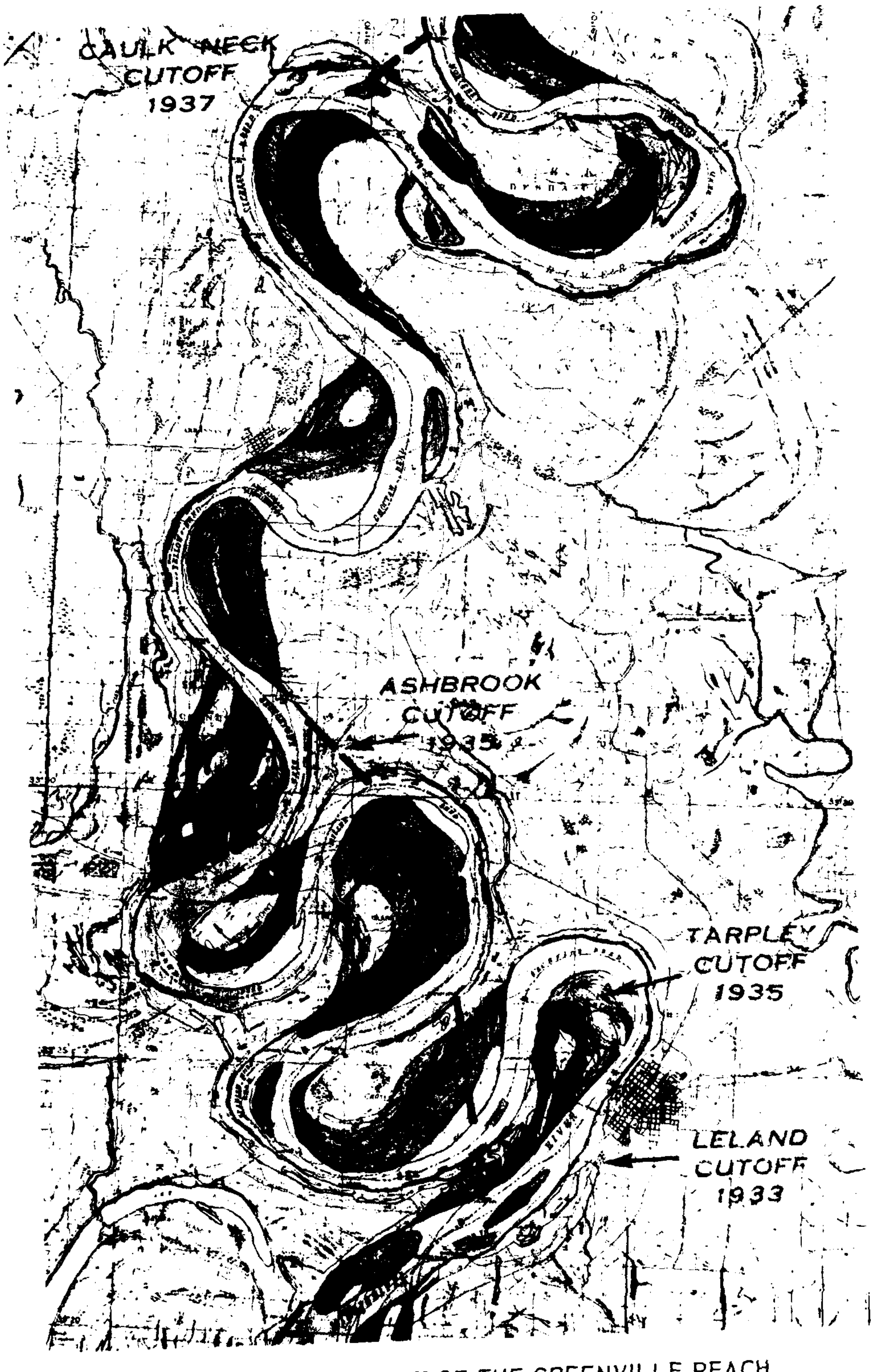
> ...nature forced our hand by making Leland Cutoff where it happened to break through. This upset General Ferguson's plan and resulted in making one more cutoff, whereas originally two short cutoffs had been contemplated to take care of the entire Greenville Bend situation. As it turned out, Tarpley Cutoff had to be made at a point where no cutoff had been planned, and its length alone exceeds that of the two cutoffs originally conceived.

Figures 21 and 22, respectively, show the historic development and the 1975 river in the Greenville Reach. Figures 23 and 24 are aerial photographs of the three cutoffs on the reach taken from 1935 to 1974.

6.08 Ashbrook Cutoff. The original length of cut was 4530 ft, and the distance around the bend was 13.3 miles. The initial slope across the cut was 15.5 times greater than that of the bendway.

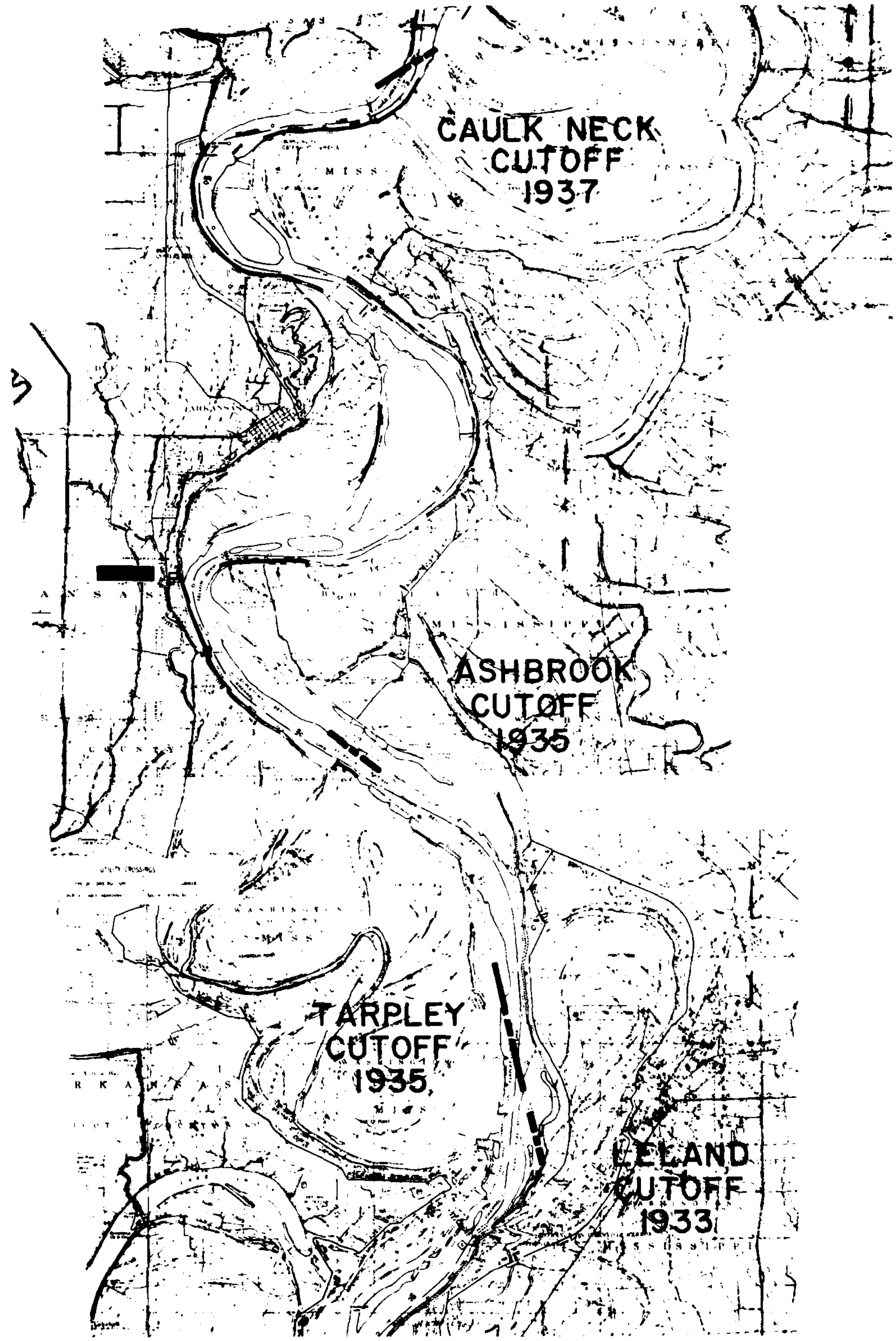
Construction of the Ashbrook Cutoff was initiated in August 1935, following the opening of Tarpley Cutoff earlier in the spring. Dredging progressed from both ends of the cut, leaving a narrow plug in the middle of the neck. This plug was removed by blasting in November 1935 after about 3,500,000 cu yd of material had been removed from the pilot cut (Table 9). The cutoff enlarged rapidly and carried 100 percent of the low-water flow in 1936. Two days after the cut was opened the steamer *Mississippi* passed downstream through the cutoff.

While considerable accretion occurred in the old channels on the west side of the river during development of the cutoff, it was necessary to close these channels by sand dikes in order to confine the flow to the new alignment. Following the construction of the three Greenville Bends Cutoffs, the channel migrated to the east and has created an extreme width of river between top of banks from the upstream end of Ashbrook Cutoff to below Leland Cutoff.



HISTORIC DEVELOPMENT OF THE GREENVILLE REACH

Figure 1



1975 MISSISSIPPI RIVER IN THE GREENVILLE REACH

Figure 22

AERIAL VIEWS OF UPPER GREENVILLE REACH (ASHBROOK CUTOFF)

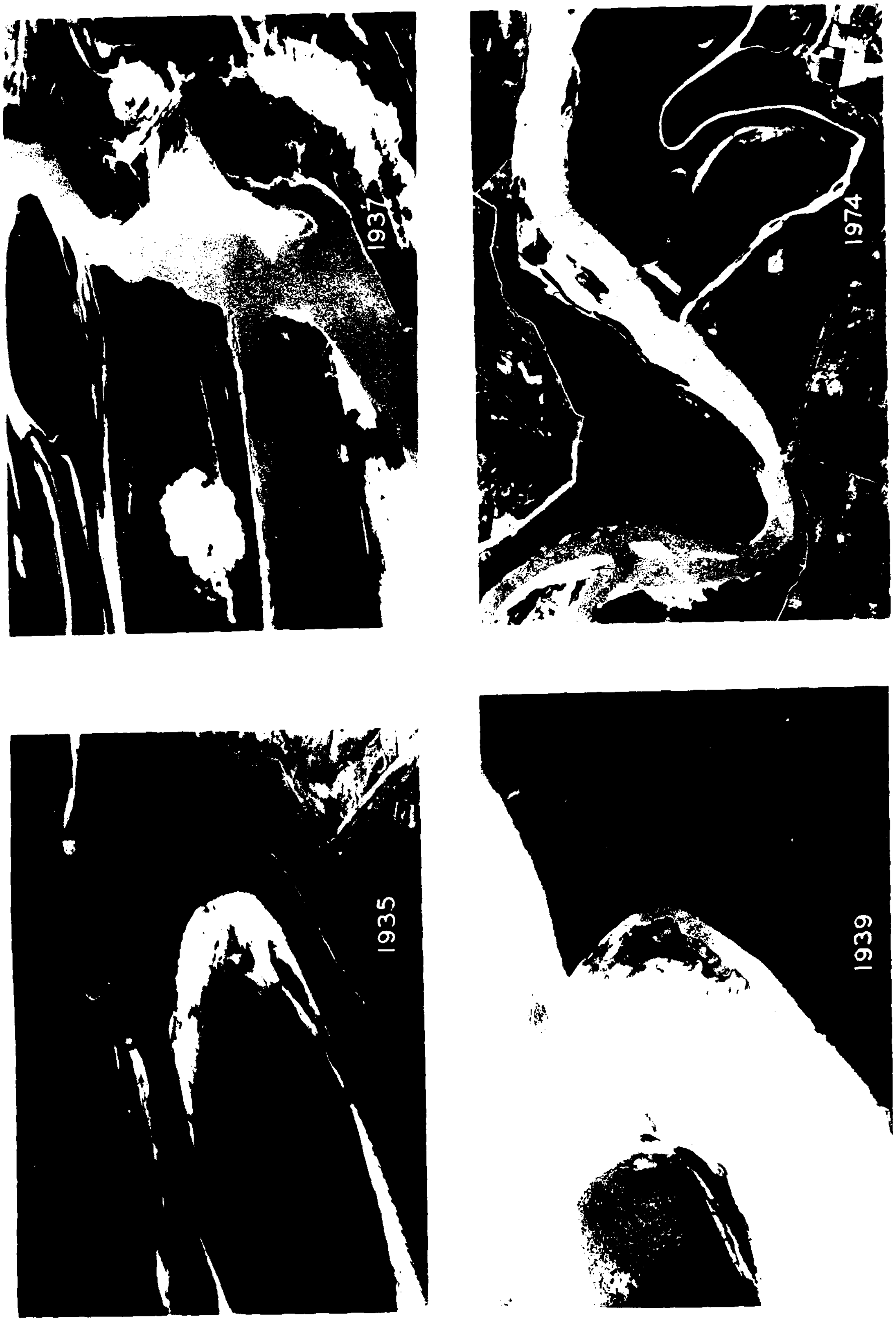


Figure 23

AERIAL VIEWS OF LOWER GREENVILLE REACH (LELAND NECK & TARPLEY CUTOFFS)

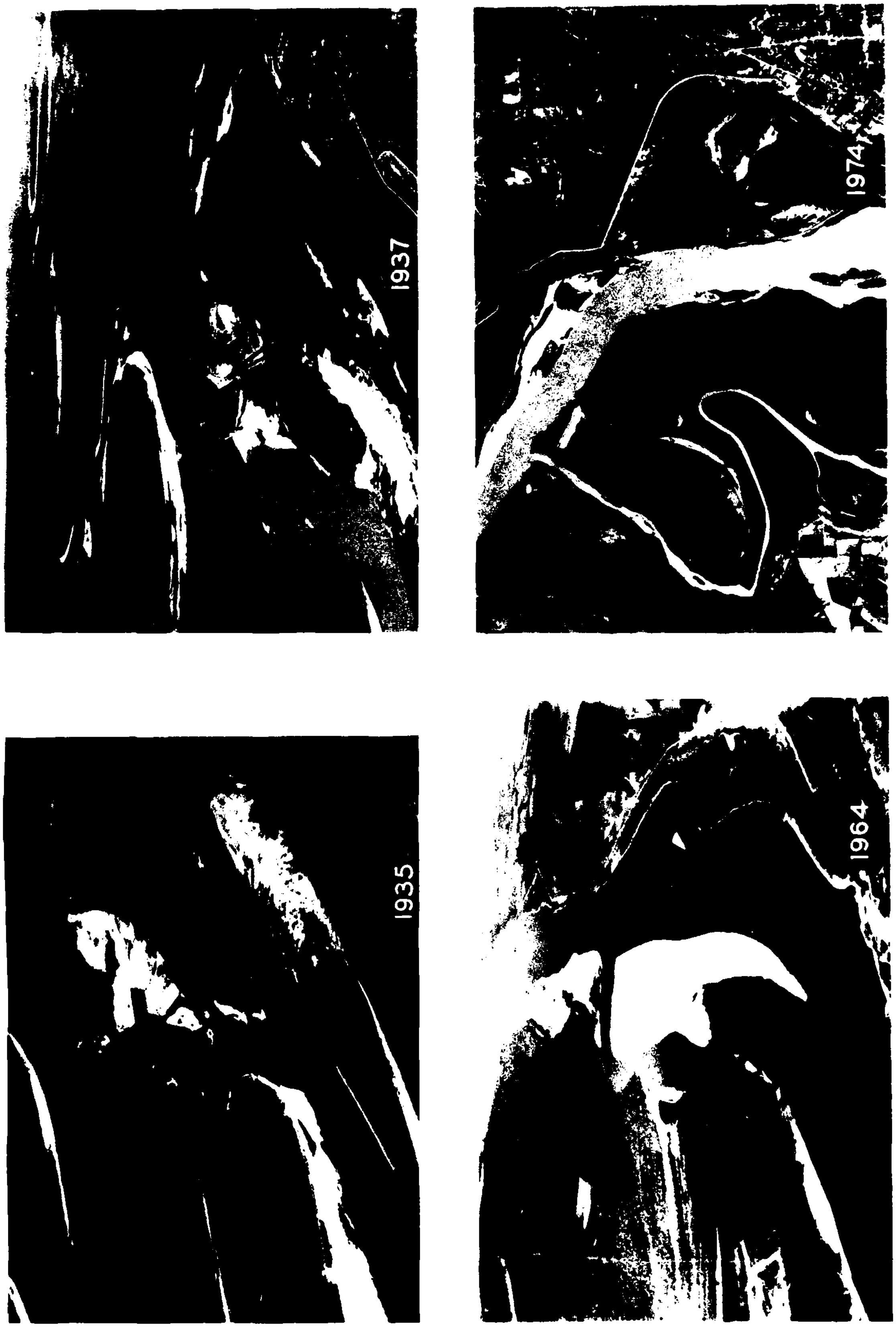


Figure 24

Table 9

Ashbrook Cutoff Development

Date	Arkansas City Gage, ft	Flow in Cutoff % Low Water	Average	High Water	Amount Dredged cu yd	Dredged Accumulation cu yd
Initial cut opened 11/19/35					3,536,618	
Opened for navigation Nov 1935						
12/3/35	8.8	35				
1/20/36	20.1		50			
4/21/36	40.3			80		
7/18/36	4.3	100				
10/16/36	8.9	88			1,678,300	5,214,918
2/18/37	53.4			87		
8/5/37	8.7	100				
11/13/37	12.7		100		1,153,903	6,368,821
1939				85		
1940					1,552,793	7,921,614
1941					1,316,008	9,237,622
1942					7,741,664	16,979,286

Concerning the Ashbrook Cutoff, Stewart states:

> This was the climax of all cutoffs. It was the last neck to be cut to complete the elimination of the Greenville Bends. Ashbrook was the farthest upstream of the series of necks in the renowned bends. It was the one which, above all others, must never be allowed to breach. It was the one over which "blood, sweat, toil and tears" had almost yearly been expended. It was the one on which almost $3,250,000 were spent on revetment and dikes to prevent a cutoff. It was the one about which, it is understood, the order was given in a comparatively recent flood to hold Ashbrook Dike even if to do so required lessening the reinforcing of the controlling levee. In other words, a cutoff in Ashbrook Neck would be more disastrous than a major crevasse in the controlling levee line.
>
> It should be said, though, that by the time construction of Ashbrook Cutoff was to begin, the fears and opposition to it had largely been dissipated. The most interested parties, that is, the residents in the area of potential effect, had noted that Leland and Tarpley Necks in the Greenville Bends had been cut off without untoward results; therefore, little apprehension remained for this last cutoff, which

would complete the shortening of distance between Arkansas City and Greenville. Before the cutoffs this distance had been 47.8 miles. Upon completion of Ashbrook Cutoff the distance would be only 12 miles....

While it was not at the narrowest section of the peninsula, it was at a location that promised the best general alignment and was only 4500 ft across....

In planning the operations it was decided that a levee machine carried on a barge would be used to remove the portion of Ashbrook Revetment from the upstream end of the line selected for the cutoff. The opening in the revetment was made wide enough to allow for adequate development of the cutoff channel. This part of the work was done in the middle of September 1935. In the meantime, the clearing and grubbing of the right-of-way were completed by a cutterhead dredge at a low river stage. The depth of the cut was about 20 ft below standard low water at the downstream end, about 13 ft below standard low water in the middle section, and about 23 ft below standard low water at the upper end. The depth of cut was varied largely due to character of material and fluctuating river stages. Stiff clay was encountered in the upper end, and some extra depth was given there in order to ensure that the bottom of the cut was in sand and that satisfactory depth by natural scour would be realized.

The dredging began at the downstream end and continued from that end for a distance of about 2000 ft. The material at that point was fine sand and would erode rapidly, so it was decided to leave the plug there. It is always desirable to leave the plug in easily erodible material so it will be certain to wash out rapidly after flow is started through it by blasting. The dredge was moved to the upstream end of the cutoff line and started excavation at that end in the opening which had been previously made through the revetment. After a few days progress, stiff clay was encountered with many old and deeply buried cypress stumps in it. This greatly retarded dredging progress. The banks of the dredge cut stood on very steep slopes until undermined by the dredge cutter, then the bank would break down in enormous slides. In order to alleviate this condition, charges of dynamite were placed in deep holes, which were spaced in a semicircle around the bank immediately ahead of the dredge. When these dynamite charges were fired, the explosion cracked the bank ahead of the dredge and loosened the material so it took a flatter slope. Then the dredge

could advance without danger. This method was continued until the stiff clay had been dredged through. Buried stumps were not encountered except in the clay. When it was passed, the material changed to fine sand again and continued so until the plug was reached. Dredging was stopped when the width of the top of the plug had narrowed to about 25 ft. At this time, the plug thickness at water surface was about 100 ft. The water surface at the upper side of the plug was 4.2 ft higher than at the lower side. It was time to blast the opening and watch the Mississippi glide through.

Dredging was finished the morning of November 19, 1935. Planting of dynamite in the plug started at once. There were many notables present for the opening. The first blast failed to open the plug to depth of water surface. Another charge was planted and blown at 12:05 p.m. This one was successful. Flow immediately started and the plug began to melt away rapidly.... By 1:30 a.m. -- less than an hour and a half after flow started -- the plug was gone and the banks of the dredge cut were caving. The velocity was increasing unbelievably fast....

Ashbrook Cutoff developed more rapidly and probably more satisfactorily than any of the others. The swift current, which naturally followed with an 11.4-mile reduction in length, decreased toward more normal proportions as the new channel deepened and widened and slope adjustments took place. In 30 days after the opening, the slopes and velocities had improved to such an extent that navigation began using the cutoff rather than make the long trip around the old bend.

A few years after the cutoff was made, enormous widening in the river above had taken place. This widening permitted bar building, which extended down into the cutoff itself. This condition did not affect the value of the cutoff to flood control but did interfere with navigation. Dredging with pump barges has been done on two or three occasions to improve the low-water navigation channel.

As a result of Ashbrook and Tarpley Cutoffs, Island 82 at the extreme end of Linwood Neck (between Ashbrook and Tarpley, and the only neck in this group which was not cut) began to recede rapidly southward, while at the same time great filling was taking place in Miller Bend, which was just below the foot of Ashbrook.

6.09 Tarpley Cutoff. The break across Leland Neck and the rapid

development of the cutoff required a change in schedule for construction of the Tarpley Cutoff. Work was commenced in January 1935 at the lower end directly opposite Leland Cutoff. The pilot cut was dredged to a depth of about 40 ft below bank height or 0-15 ft below mlw and was completed in April 1935, about the time of the crest of the high water of that year.

The length of the cut was 13,000 ft, and the bendway was 12.2 miles, making the original slope through the cut five times as great as that around the bend. Because of the steep slope across this cut and the sandy soil in which the cut was located, the new channel initially developed rapidly, but the channel later developed many bars and tended toward a braided condition. As a result of this, much dredging was needed in the reach for the next several decades.

Stewart describes the cutoff developed as follows:

> The Tarpley Cutoff was made across Tarpley Neck, which is the next one upstream from Leland Neck and from the lower end of the Greenville Bends....The cutoff was not made across the narrowest part of Tarpley Neck. The location was selected to meet the upstream end of Leland Cutoff, which had already been functioning for nearly two years.
>
> At gage readings that somewhat surpassed bank-full, there was flow across the neck prior to the cutoff. This overbank flow had begun to scour "blue holes," which are the result of overbank flow, at high velocities, finding soft, easily erodible spots in the high ground and gouging it out to form a deep lake. These lakes are called "blue holes" because the water has a bluish appearance after the settling out of sediment. They obviously weakened the narrow necks and added to the apprehension of the many who feared so greatly the breaching of any of the peninsulas of the "Greenville Bends." [Figure 19 is a copy of a telegram from General Brown on preventing a cutoff at Tarpley.] This fear led to the filling of the Tarpley "blue holes" with sand dredged from the river in the early part of 1932 to reinforce the neck against a natural cutoff. Also in early 1932, about 1700 linear ft of concrete revetment was placed at the upstream side to protect the bank against caving at what was considered the weakest point. The filling of the "blue holes" with sand is

a measure which cannot be readily justified for cutoff prevention. Elementary reasoning would make it plain that the same forces which gouged out the erodible material to create the original "blue holes" would do the same thing to the sand with which they were filled as soon as a river stage occurred which would permit flow over the neck again. This is exactly what happened here. The reasoning which led to this fill may be called "panic engineering." Happily, the fill was not replaced, as by late 1932 Tarpley Neck was being studied as the location for a future cutoff.

Construction of the cutoff was begun early in 1935 with a dustpan dredge digging through the sandbar which formed at the lower side of the neck as a result of Leland Cutoff. Immediately after the opening at Leland, the upstream end of the old river bend around Leland Neck began one of the most rapid natural fills ever observed in the district. Due to the fact that Tarpley Cutoff was to be aligned to Leland, the downstream end of Tarpley Cutoff would cross the upper portion of this enormous opening and rapid fill. Inasmuch as this deposit was all sand, a dustpan dredge could advantageously dig this portion of the cutoff channel. The cut extended about 3000 ft until it reached the main high bank of Tarpley Neck. At this point a cutterhead dredge took up the heavy work.

The work progressed steadily and uneventfully, making a cut from 250 to 300 ft wide, with depth ranging from standard low-water elevation to about 15 ft below standard low water. The river stage gradually increased until it reached an elevation about 5 ft above bank-full. This, or course, made it impossible to dredge as deep as we had now learned was advisable, but due to none of the material being particularly resistant and the shortening of distance being so great, it was felt that development would not be retarded.

The depression of the deepest "blue hole" will be noted about 2000 ft from the upper end of the cutoff. Then, about 3000 ft from this end a much smaller depression of one of the smaller "blue holes" is evident. Lesser depressions connected these to the main river above. When the river rose to a little below bank-full, water flowed through these depressions and found its way through devious paths to the main river at the downstream side of the neck.

By the time the dredge had progressed almost to the smaller "blue hole" mentioned above, the river had risen so much that flow was running through the depressions and into the new cut. This created current in the completed portion of the cutoff which caused some inconvenience to operations. It was therefore decided to move the dredge to the upper end of the cut and work toward the lower end, leaving a narrow plug between the two dredge cuts. The plug would be blasted out with dynamite to complete the cutoff. By the time the dredge had advanced about 1700 ft from the upstream end, a considerable scour had taken place along the line of the cut between the big "blue hole" and the dredge cut made from the lower end. In view of this scour, it was determined that dredging in that section would not be necessary. A plug was then left between the upper side of the big "blue hole" and the upper cut. The plug was about 125 ft thick. A ditch about 3 ft deep and 3 ft wide was blasted through the plug with dynamite in the late afternoon of Easter Sunday 1935, and Tarpley Cutoff was made. It was a revelation to watch the widening and deepening of this small ditch. No one could see it without marveling at the striking power of this river. Within a few hours of the blasting, the undredged section of the cut had enlarged to the size of the dredged portion, and by the next day it looked as if all the Mississippi River was flowing through the new Tarpley Cutoff; although of course that was not nearly the case. Anyway, the second of the Greenville Bends had been eliminated and still no disastrous results had been realized.

Later in 1935 and again in 1937 sandbar formation occurred at the lower end of Tarpley where it entered the main river at the head of Leland Cutoff. The cross-section area here was far greater than the cutoff area, and fill was a natural result. Dredging with pump barges was done in both the years mentioned above for approximately one month.

Table 10 summarizes the data on the development of this cutoff.

6.10 Leland Neck Cutoff. A natural cutoff across Leland Neck, which would divorce Bachelor Bend and Greenville, Mississippi, from the low-water channel, had threatened for many years and had been prevented only by concreted action in revetting the bank and constructing a dike along the neck to intercept high-water flow. Toward the end of the 1933 high water, a break occurred in the pile dike, and a cutoff channel

Table 10

Tarpley Cutoff Development

Date	Greenville Gage, ft	Flow in Cutoff % Low Water	Flow in Cutoff % Average	Flow in Cutoff % High Water	Amount Dredged cu yd	Dredged Accumulation cu yd
Initial cut opened 4/21/35					6,059,046	
4/22/35	44.1			5		
7/2/35	43.3			46		
7/31/35	16.9		48			
Opened for navigation Nov 1935						
12/4/35	7.6	66				
3/11/36	26.0		58			
5/2/36	39.4			58		
7/29/36	0.8	89				
10/15/36	7.7	89				
11/13/36	15.7		77			
2/12/37	52.0			60		
3/7/37	42.4			78		
5/7/37	26.8		78			
11/17/37	7.5	89			1,016,550	7,075,596
1938		65-76				
1939			65		28,158	7,103,754
1940					1,165,813	8,269,567
1941					7,649,556	15,919,123

developed most of the way across the narrow neck. To align this channel properly, a section of the pile dike was removed, and a land machine cut was made at the upper and lower ends of the channel.

Concerning this cutoff, Clemens states:

> A cutoff at Leland Neck had threatened for many years. To prevent this, various dikes had been built on the point and a considerable amount of revetment had been placed on the upper side of the neck. In 1930, a pile dike was built on the point during high water to prevent the river breaking through into some old blue holes that had been formed by the 1929 high water. Towards the end of the 1933 high water, a break occurred in this pile dike, and a cutoff channel was opened most of the way across the point. To align this channel properly, a small amount of additional excavation was made, which resulted in a low-water channel across the point. This developed rapidly and carried about 50 percent of the flow during the 1933

> low-water season. Following the opening of Tarpley Cut during the 1935 high water, further development occurred, and all of the flow passed through the cut during the latter part of the 1935 low-water season. This cut has relieved the attack on Greenville front and places Greenville on an oxbow lake, a short distance from the main river.

The length of the cut was 4600 ft, and the bendway was 11.2 miles, making a 13:1 ratio of slopes. Subsequent dredging in the 1938-45 period (Table 11) was probably due to braided stream conditions, plus the excessive amount of sediment moving down from Ashbrook and Tarpley Cutoffs.

It was necessary to construct the Greenville Harbor Dike about 6 miles long to prevent further silting of the bendway and Greenville Harbor and to confine the high-water flow to the new channel. Subsequently, one setback has been required in this dike because of excessive caving in Miller Bend.

Table 11

Leland Neck Cutoff Development

Date	Greenville Gage, ft	Flow in Cutoff % Low Water	Average	High Water	Amount Dredged cu yd	Dredged Accumulation cu yd
Natural cutoff opened 7/8/33						
7/31/33	8.8	24				
9/18/33	7.9	39			272,000	
1/22/34	20.3		42			
4/9/34	32.0			42		
Opened for navigation 6/7/34						
11/27/34	7.8	64				
4/4/35	45.4			50		
6/25/35	43.4			70		
7/23/35	24.0		83			
9/6/35	8.2	97				
9/30/35	3.7	100				
4/30/36	40.7			83		
6/3/36	8.7	100				
1/27/37	39.6			100		
1938					4,889,075	5,161,075
1940					7,188,514	12,349,589
1941					332,500	12,682,089
1945					989,980	13,672,069

The new length of river through the Greenville Bends was only about one fourth as long as the original bendways distance. The resulting extreme slope change has caused an unstable condition that still persists. Much revetment and dike work has been required in an effort to hold the river in its new alignment. In spite of millions of dollars in construction and in dredging, the river is trying to return to its original sequence of pools and crossings. Figure 20 compares the geometric pattern of the 1933 and the 1975 river. The same number of pools, crossings, and bars exist today as in 1933 and they are orientated on the same side of the river.

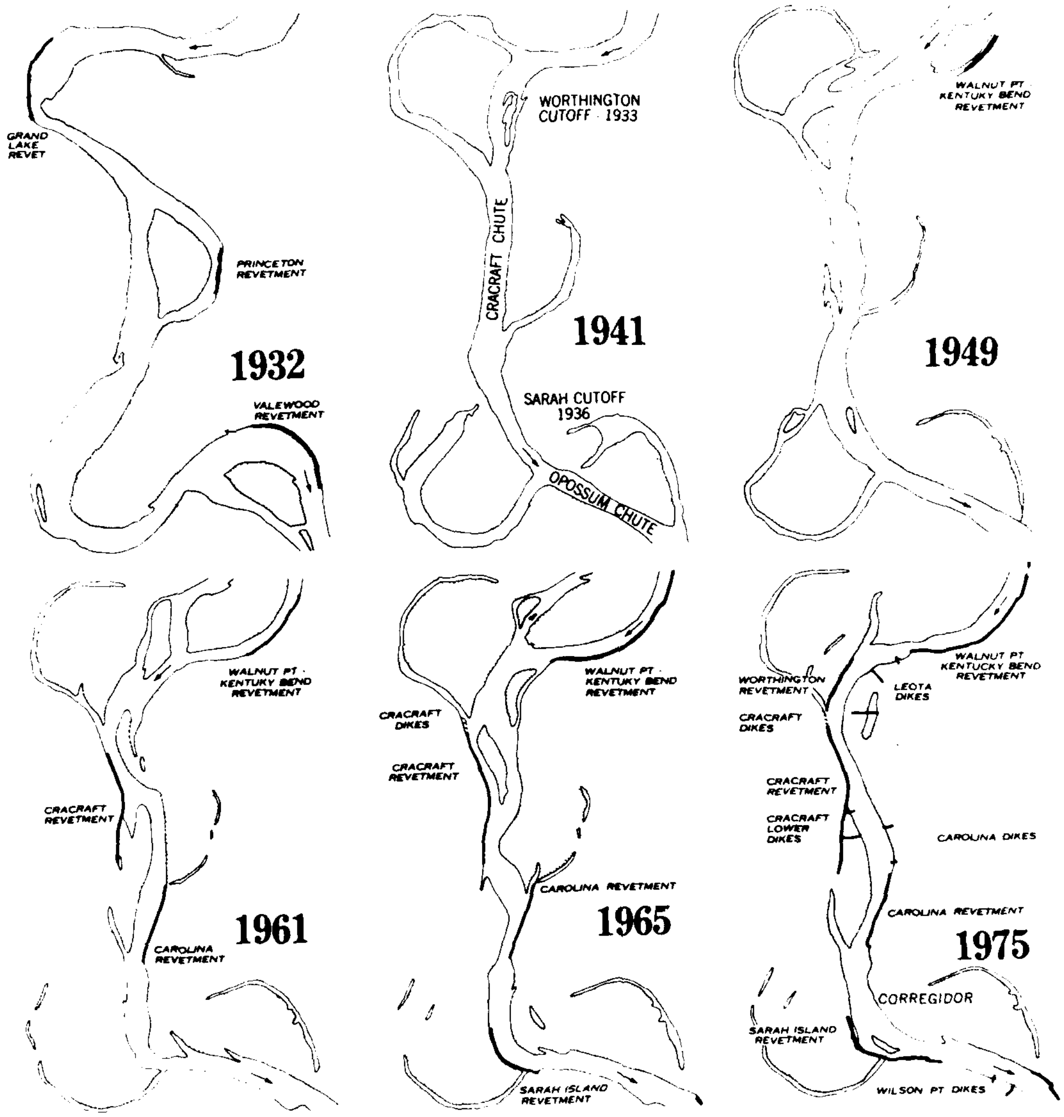
The extreme amount of dredging (Tables 9, 10, and 11) in the early 1940's was probably due to the steep slope imposed by these three Greenville Cutoffs, forcing the river into a braided condition.

6.11 Kentucky Bar-Mayersville Reach. This stretch of river was shortened much the same as the Greenville Reach just a few miles upstream. The combined effect produced a braided type stream from the upper end of Choctaw Bar (1962 Above Head of Passes (AHP) mile 566) to Mayersville (AHP mile 496). This 70-mile reach of river averaged 125 miles in length over the past 400 years. Today some self-maintaining control is being regained, but only in the reaches where proper sinuosity and alignment have been rebuilt into the river.

Cracraft and Opossum chutes were developed to align Worthington and Sarah Cutoffs with the river upstream and downstream (see paragraphs 6.02 and 6.03). Figure 25 is a time-lapse sequence of the planview of the Kentucky Bar-Mayersville Reach from 1932 to 1975. The reach became braided in form and required much maintenance dredging until an alternating sequence of properly spaced bars was established. Future dikes are to be built at Corregidor Point opposite Sarah Island revetment (1975 map, Figure 25).

Stewart describes the development of this reach as follows:

> A glance will indicate the relative positions of Kentucky Bend and Worthington Cutoff. In 1937, when the first work was undertaken, Kentucky Bend was fairly deep and easy, but the point bar in front of Island 86 was encroaching gradually toward the



1932-1975 DEVELOPMENT OF THE KENTUCKY BAR - MAYERSVILLE REACH

Figure 25

> concave Mississippi shore. This shore was gradually receding. Recession of the bend southeastward tended toward even more unfavorable entrance to Worthington Cutoff.
>
> In the high-water season of early 1937, a marked tendency toward the development of a secondary channel across the convex bar was noted. It appeared advisable to encourage the growth of a new channel here to end the recession of the Mississippi shore and to improve the directive to Worthington Cutoff. Dredge cuts were made in 1937 and 1938. In view of the current running across the point bar only at high stages and returning to the bend channel at low stages, the point channel filled and no evidence of it remained by early 1940....
>
> It is felt that the successful development of the point channel could have been accomplished had we been able to throw enough equipment in the attack. This was not a case of "too little - too late" but only of too little and not long enough. The work done was at the proper time, but due to there being so many other locations needing immediate attention, work at this place was ended with the hope that further natural action would continue the new channel's development.
>
> In the light of subsequent events, it is unfortunate that we did not follow up the advantage in making the point channel at Kentucky Bend because the rate of encroachment in the bend by the convex bar has rapidly increased resulting in large-scale caving of the Mississippi shore, which is now several hundred feet further south. This movement has resulted unfavorably to Kentucky Bend and has made even more unfavorable entrance to Worthington Cutoff. In the not too distant future, it will probably be necessary to undertake a large project to make a channel across the point bar without the initial assistance of the river. It can be done, but will certainly require prodigious effort.

During the following decade, many millions of cubic yards were dredged in an effort to develop the chute channel. The result was the development of a permanent divided flow situation.

6.12 Worthington Point Cutoff. The length of cut here was 17,600 ft, and the bendway was 8.1 miles long, making the slope through the initial cut 2.43 times as great as around the bend.

Concerning this cutoff, Stewart states:

> Worthington Cutoff was made across the neck of land called Worthington Point.... This construction was begun in September 1933. As compared with the long meanders, which were the Greenville Bends, the meander around Worthington Point was relatively short. The principal reason for its selection as the location for a cutoff was that the controlling levee on the Arkansas shore at Matthews Bend, which is the bend around Worthington Point, was in danger from caving banks. This main levee line was close to the top bank, and to remove the levee to a line farther inland would have been highly expensive. Another alternative, which would also have been very costly, was to renew the long revetment in Matthews Bend, which was rapidly failing. In addition to the initial costs of either of these alternatives, there still would have remained the lack of assurance that the line could be held permanently. A cutoff across Worthington Point would completely relieve the apprehension with regard to the controlling levee by bodily moving the river away from Matthews Bend. A further important point in the selection of Worthington Cutoff was that it was felt that one in that general vicinity was desirable as a part of the longer range program of lowering flood heights by improving the channel of the river.... The location for the entrance to the cutoff was apparently too far downstream. This resulted in the cutoff channel making nearly a right angle in leaving the main river channel. All of these points are not conducive to the most effective development and operation of a cutoff, and this one produced all of the difficulties which we have learned now should be expected with the existence of such conditions. To begin with, the manner of constructing the cutoff channel was one which we have since learned is not generally practicable nor economical. This was, by the use of tower levee machines, to excavate a pilot ditch along the line selected for the cutoff. It was felt that by the construction of a pilot ditch, in the dry, by land machines, the required material movement would be held to a minimum. Then, when high river stages occurred, water would flow through the pilot channel with sufficient velocity to enlarge the pilot ditch to the expected proportions. The bottom grade to which the pilot ditch was excavated by the land machines was 8 ft above standard low water. Later developments proved that our reasoning was very faulty. The pilot channel was completed

in the latter part of December 1933, and the river stage shortly thereafter rose sufficiently for water to flow through the new cut. But instead of enlarging, both in depth and width, the amount of flow through it was relatively so small that no development whatever occurred. In fact, a large section of the pilot channel actually received fill. It then became obvious that a much larger opening through the neck would be required to attract the main flow of the river. In the spring of 1934, a dredge was placed at the upstream end of the cutoff, and a continuous dredge cut was made throughout its length. This cut was made to a depth of approximately 10 ft below standard low water.... In the following high-water period, it was noted that the purpose of relieving the current attack in Matthews Bend had been definitely accomplished, but it was also easily apparent that the cutoff channel was still not developing to anything like total river proportions. The direction of flow in the main river at the entrance to the cutoff was still such that flow was directed past the cutoff into the bend channel rather than directly into the cutoff. For this reason it was difficult for large quantities of the discharge to enter the cutoff. The water that did enter seems to have exerted every effort to pass the entrance to the cutoff and then at the last moment decided that it would go that way.... All this time velocities through the cut were too low to cause scour of any magnitude. Shoal places were numerous throughout the length of the cut. It was next decided to attempt to move the entrance, it being felt that if sufficient water were induced to enter the cutoff, velocities would be high enough to cause the required scour throughout the length....

After the high-water season in the spring of 1936, and presumably as a result of continuous dredging through the left-hand bar at the upper end of the cutoff, the new channel showed considerable improvement. The percent of discharge had increased to 29. The left-hand bar persisted in building. Further dredging through this bar and the removal of a large portion of the main left bank at the upper end were decided upon...Since 1936, Worthington Cutoff has gradually developed toward the full river capacity. However, in this period of development, there has been enormous recession of the west or right-hand shore of this channel. This westward movement has totaled about 2500 ft at the upstream end. The right

> bank recession at the lower end was not of great consequence until 1942, at which time the westward movement at the upstream end had nearly ended. The right bank at the lower end moved westward approximately 1000 ft. It cannot be foretold at this time at what point the west bank of this cutoff will stabilize itself. It cannot be denied that the cutoff is functioning, but it cannot be stated with assurance that future measures will not be required to arrest the westward movement.
>
> During the years of construction and development of Worthington Cutoff, the development of Cracraft Chute immediately downstream from the lower end of the cutoff had been proceeding. It may be significant to note that the definite important development of Worthington Cutoff did not begin until the improvement of Cracraft Chute was far advanced. It is highly probable that the increase in flow through Cracraft Chute created sufficient "draw" through Worthington Cutoff to materially aid in its enlargement.
>
> The final effectiveness of Worthington Cutoff goes far to prove that with sufficient persistence and singleness of purpose much can be done toward the control of the channel of the Mississippi River.

This statement is the key to any successful results that have been derived from the past 40 years of effort; i.e., the success is largely a result of an extreme amount of work in forcing the situation. Continued success can be achieved by further forcing the river, but it is believed that proper alignment will aid in developing a more self-maintaining channel. Table 12 gives pertinent data on the Worthington Cutoff development.

Table 12

Worthington Point Cutoff Development

Date	Greenville Gage, ft	Flow in Cutoff % Low Water	Flow in Cutoff % Average	Flow in Cutoff % High Water	Amount Dredged cu yd	Dredged Accumulation cu yd
Initial cut opened 12/25/33					3,580,265	
4/10/34	32.5			3		
6/28/34	6.7	3			8,000,000	11,580,265
1/24/35	24.2		13			
4/5/35	45.4			17	1,656,147	13,236,412

(Continued)

Table 12 (Continued)

Date	Greenville Gage, ft	Flow in Cutoff % Low Water	Average	High Water	Amount Dredged cu yd	Dredged Accumulation cu yd
9/7/35	7.6	7			4,598,537	17,854,944
1/25/36	23.6		20			
4/25/36	40.9			29		
6/10/36	7.3	19			1,055,273	18,890,222
2/2/37	46.8			31		
3/4/37	45.3			42		
Opened for navigation Apr 1937						
6/3/37	20.8		47			
8/4/37	7.7	46				
10/11/37	-0.3	48			8,636,244	27,526,466
1938		74			439,208	27,965,674
1939				67		

6.13 Sarah Island Cutoff. The length of cut was 12,600 ft, and distance around the bendway was 8.5 miles, making an initial slope of 3.56 times greater than the old bendway.

Stewart describes its development as follows:

> Its upstream end was laid out to conform with the downstream end of Cracraft Chute, and its downstream end was located to conform with the upper end of Opossum Chute. Sarah Island was not a particularly long neck. The river around its point was called Louisiana Bend. The distance around was 8.5 miles; the distance across the neck on the cutoff line was 2.4 miles. The difference in water-surface elevation between the upper and lower sides of the neck averaged 2.2 ft at high water stages and 3.0 ft at low water. It was decided not to construct a pilot ditch at Sarah Island with levee machines, depending on natural scour to develop the cutoff as had been done previously. It had been learned that generally this policy was false economy due to the fact that frequently the small pilot channel would not develop unaided, and subsequent dredging to enlarge it was necessary.
>
> Right-of-way, clearing and grubbing for Sarah Island Cutoff were completed in the early part of 1935, and dredging began in May 1935 at the upstream end.... The progress went on uneventfully until the cut from

the lower end almost met the cut from the upstream end. A small plug was left between the two cuts and the dredging equipment was moved out into the main river. Dynamite charges were then placed in the plug, which had a thickness of about 50 ft, and an opening was blasted. Water immediately started flowing through. The new channel widened rapidly but did not gain materially in depth. At the end of the high river stage which occurred after the opening of the cutoff, it was noted that deepening still had not occurred. In the low-water period which followed, flow through the cutoff channel stopped completely. It is well to consider here the depth to which the original cut was dredged. This depth was to approximately standard low-water elevation, with some sections being a little below that depth. It became immediately obvious that further dredging to greater depth was necessary if the cutoff was to function at any except high stages of the river. In the summer and fall of 1936, the dredges made another cut throughout the length [Table 13]. This cut was made to a depth of approximately 30 ft below standard low water. After this deepening, no further trouble was encountered in getting major flow through the cutoff. Additional dredging was done in 1937 to improve the entrance and to remove heavy gravel deposits which were present near the upstream end....

Table 13

Sarah Island Cutoff Development

Date	Lake Providence Gage, ft	Flow in Cutoff % Low Water	Flow in Cutoff % Average	Flow in Cutoff % High Water	Amount Dredged cu yd	Dredged Accumulation cu yd
Initial cut opened 3/23/36					6,854,692	
4/28/36	37.9			12		
6/10/36	6.2	1			3,771,268	10,625,960
1/5/37	9.0	15				
2/11/37	46.9			25		
3/24/37	23.9		34			
5/19/37	31.2			41		
6/18/37	17.2		43			
8/3/37	6.4	44				
Opened for navigation Nov 1937						
12/11/37	-0.5	59			2,919,987	13,545,947
1938			84	94		
1939				65	34,772	13,580,719

> This project taught us that, in general, a cutoff should be made at less than half bank-full stages. Low water would be still better. This would permit one deep dredge cut to be made throughout the length of a cutoff, thus giving the assurance that another cut would not be required due to insufficient depth of the first cut. Several of the cutoffs in this district required deepening by dredging after their original opening. We desired to dredge no deeper than necessary in the construction of a cutoff for economy's sake and to get the cutoff open as quickly as possible. Our reasoning was faulty, both from the economic and practical views, as a deeper cut, even though it would have been slower, would in most cases not have required any further major attention.

Worthington and Sarah Cutoffs (Figure 25) were only two elements in the plan to "improve" this reach of river. Development of Cracraft and Opossum Chutes (see paragraphs 6.02 and 6.03) completed the realignment. The past history of this reach is at variance with the imposed conditions. The result has been a reach that required much maintenance dredging until recent dike construction. Figure 26 shows the river length over the past 700 years; it should be noted that today's river is less than half the length of the natural river. Figures 27 and 29 are of the historic river development and Figures 28 and 30 of the 1975 river in the upper and lower section of this reach, respectively. Figures 31 and 32 are 1935 to 1974 aerial photographs of this reach.

6.14 <u>Willow Point Cutoff</u>. The cut was 22,000 ft including the channel dredged across the sandbar. The actual bank to bank cut that would have been influenced by the high water was 12,300 ft long, and the distance around the bendway was 12.4 miles, making the high-water slope across the neck 5.32 times greater than around the bendway.

Concerning the Willow Point Cutoff, Stewart states:

> The line selected for the Willow Point Cutoff was a little toward the base of the neck from the narrowest section. This necessitated a somewhat longer cut but gave the assurance that the flow would enter the new channel without directive difficulties. It will be noted that approximately two thirds of the cutoff was in what may be termed the main bank. The lower one third was across a large sandbar which had

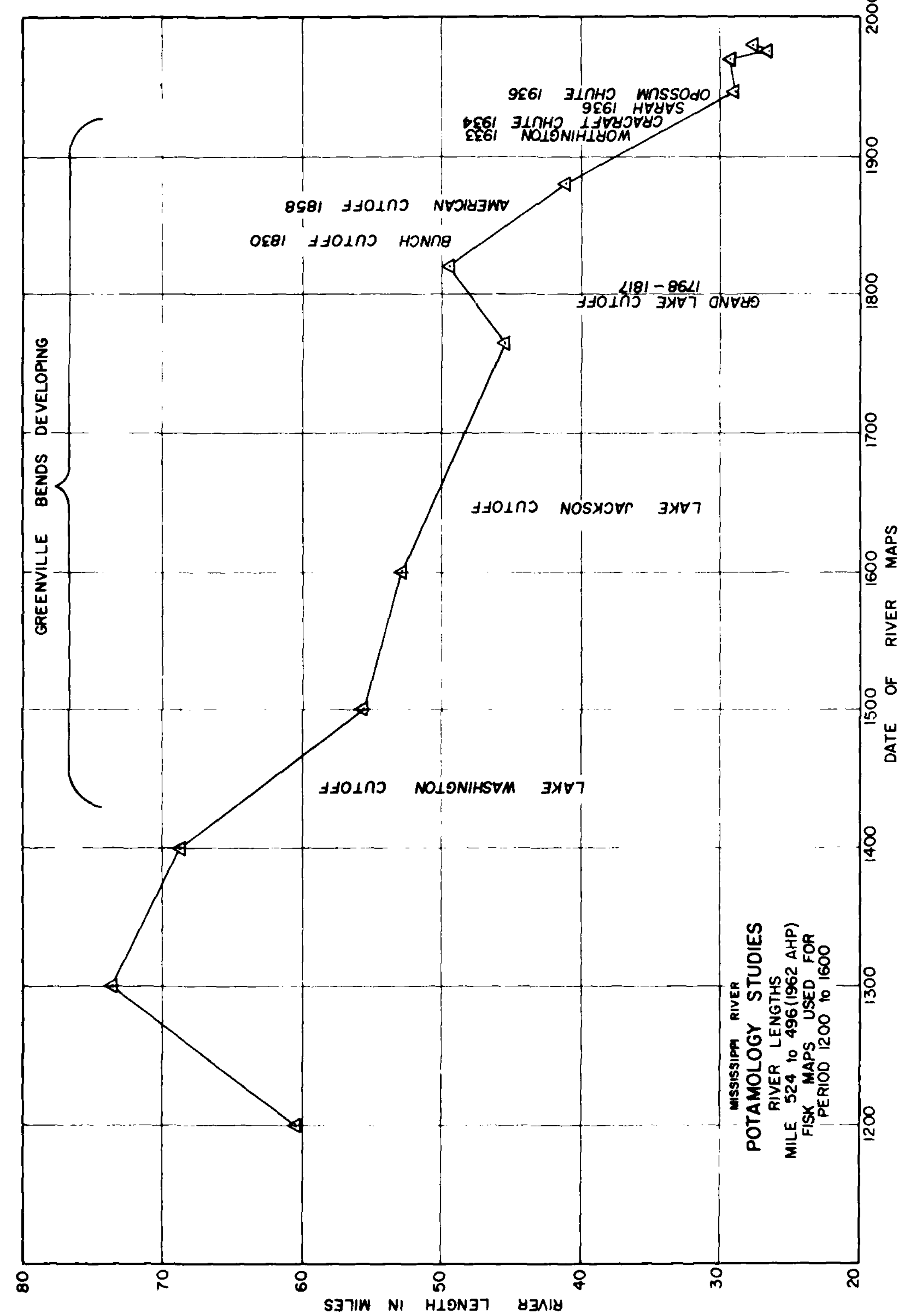
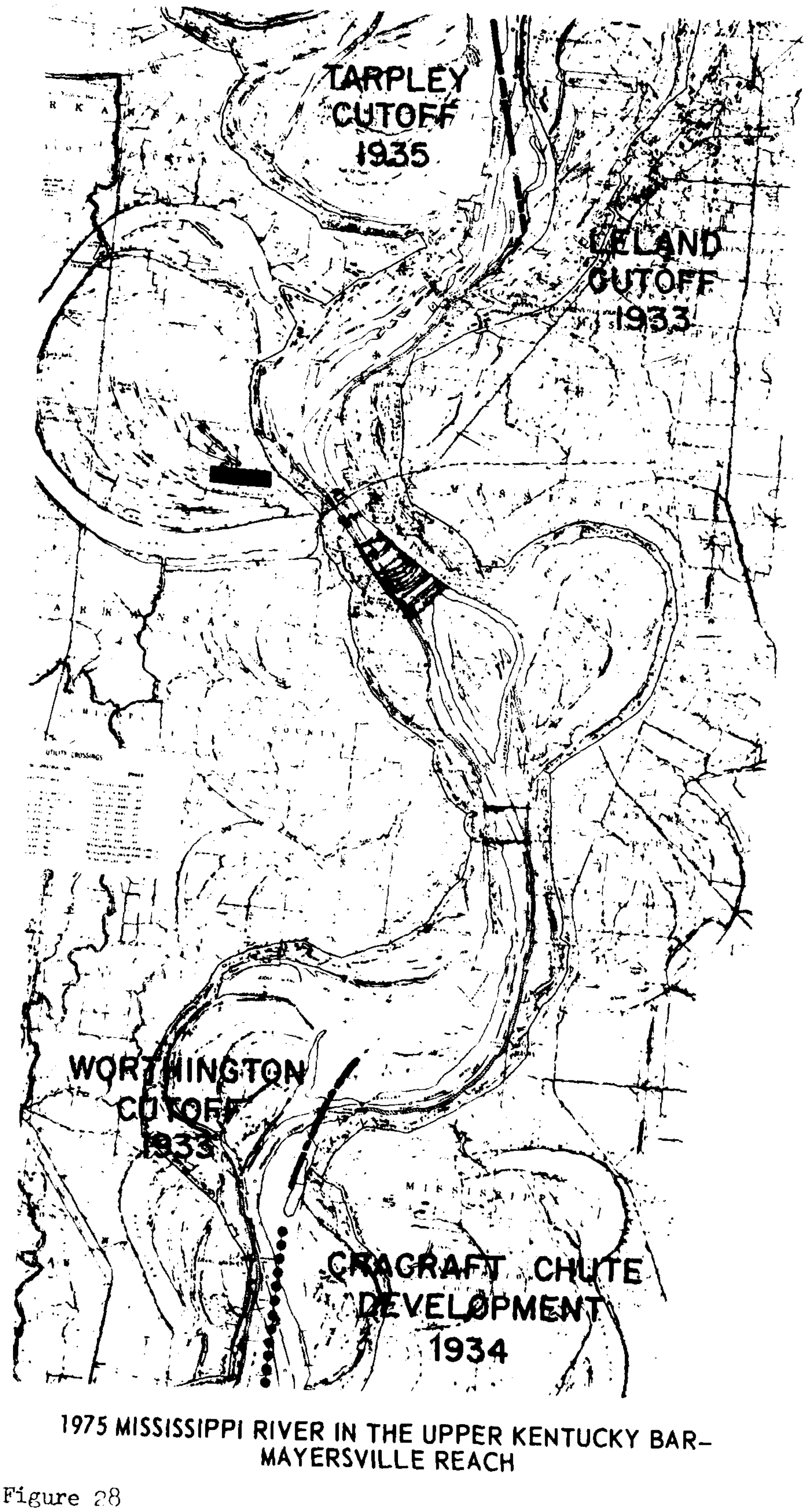

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
RIVER LENGTHS
MILE 524 to 496 (1962 AHP)
FISK MAPS USED FOR
PERIOD 1200 to 1600
GREENVILLE BENDS DEVELOPING
LAKE WASHINGTON CUTOFF
LAKE JACKSON CUTOFF
GRAND LAKE CUTOFF
1798 - 1817
BUNCH CUTOFF 1830
AMERICAN CUTOFF 1858
WORTHINGTON 1933
CRACRAFT CHUTE 1934
SARAH 1936
OPOSSUM CHUTE 1936
RIVER LENGTH IN MILES
80
70
60
50
40
30
20
DATE OF RIVER MAPS
1200
1300
1400
1500
1600
1700
1800
1900
2000

Figure 26

HISTORIC DEVELOPMENT OF THE UPPER KENTUCKY BAR–
MAYERSVILLE REACH

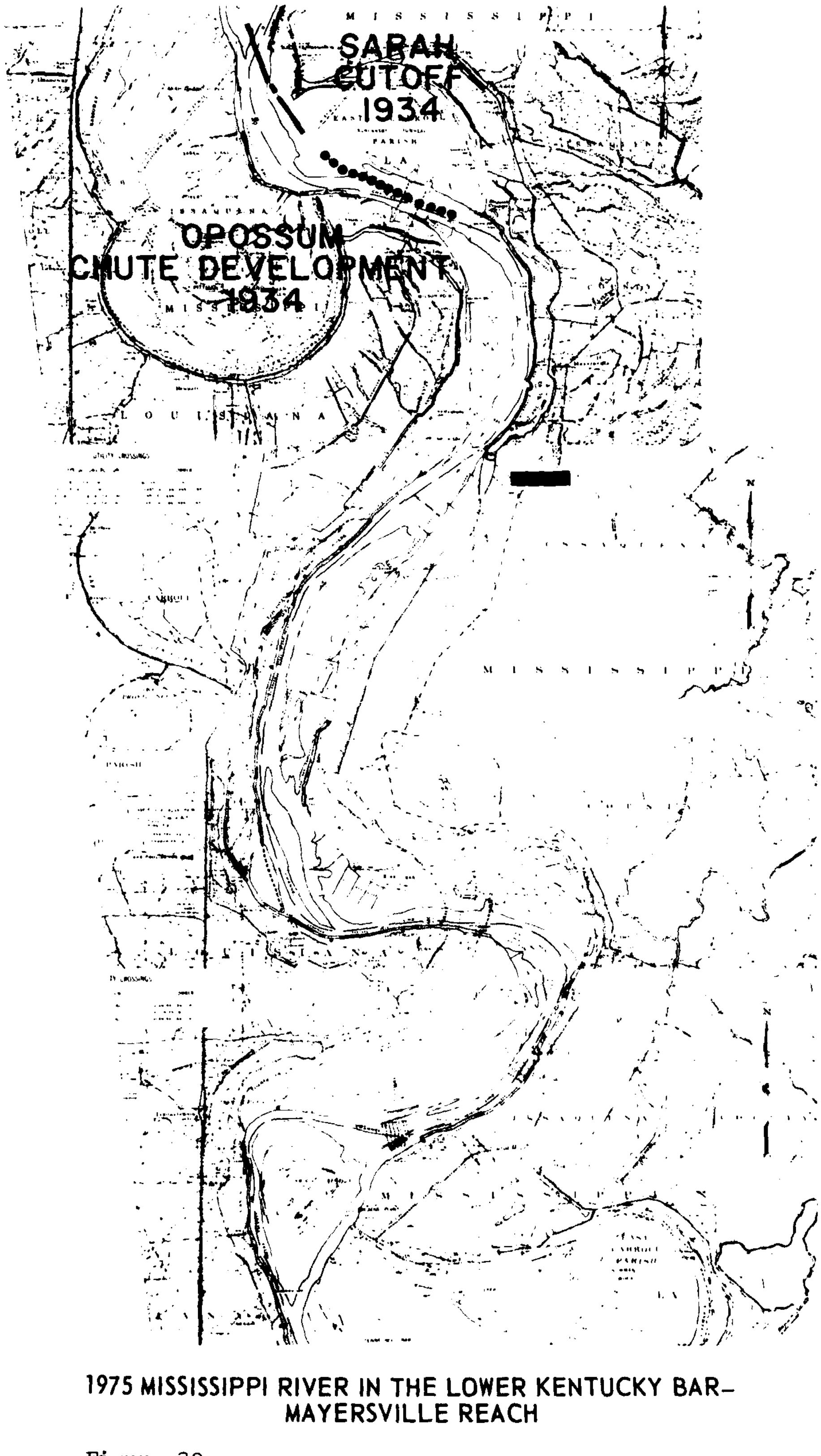
Figure 17



1975 MISSISSIPPI RIVER IN THE UPPER KENTUCKY BAR–
MAYERSVILLE REACH

Figure 28

HISTORIC DEVELOPMENT OF THE LOWER KENTUCKY BAR-
MAYERSVILLE REACH



1975 MISSISSIPPI RIVER IN THE LOWER KENTUCKY BAR–
MAYERSVILLE REACH

Figure 30

AERIAL VIEWS OF WORTHINGTON POINT CUTOFF

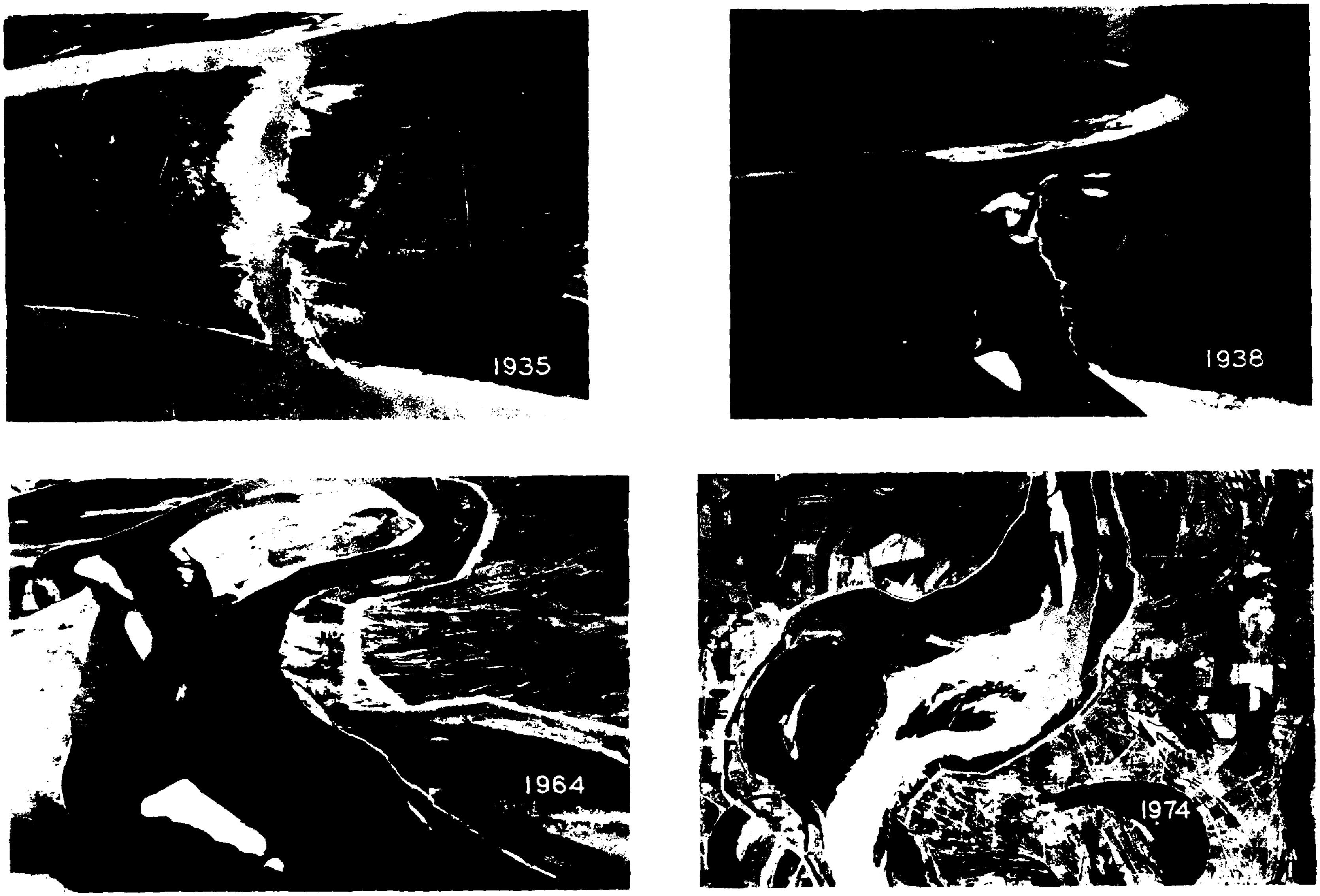


Figure 31

AERIAL VIEWS OF SARAH ISLAND CUTOFF

Figure 32

formed on the downstream side of the neck. The plan of operation was to use land machines for the excavation of a pilot ditch across the high main bank and then to allow the flow through the cutoff to find its own channel through the sandbar. Operations with the land machines were commenced in the latter part of November 1933. They progressed to January 1934, at which time the pilot channel through the main section of the neck was completed. Shortly after that time, the river stage rose sufficiently for flow to pass through the pilot channel, but very little development occurred. The retarding factor was determined to be the presence of a heavy formation of very stiff clay close to the upstream end of the cut. It was immediately obvious that dredging would be necessary to open a channel through this clay deposit. Accordingly, the cutterhead dredges were assigned the task of making the cut through the clay. The dustpan dredge Jadwin and the cutterhead dredges Catt, Lake Fithian, and Barnard worked on this cut upon different occasions during the remainder of 1934 [Table 14]. The Lake Fithian and Catt also made cuts in the pilot

Table 14

Willow Point Cutoff Development

Date	Vicksburg Gage, ft	Flow in Cutoff % Low Water	Average	High Water	Amount Dredged cu yd	Dredged Accumulation cu yd
Initial cut opened 4/8/34					7,493,091	
4/10/34	33.9			8		
6/16/34	5.0	2			3,237,368	10,730,459
1/27/35	27.2		15			
4/16/35	48.2			27		
11/6/35	5.2	52			594,500	11,324,959
Opened for navigation Nov 1935						
5/2/36	43.9			42		
11/6/36	5.6	74			650,000	11,974,959
1/31/37	20.0		45			
2/24/37	55.2			56		
3/14/37	43.8			66		
10/9/37	-0.9	99				
11/22/37	4.4	97			1,193,600	13,168,559
1938					1,092,200	14,260,759
1939		100		80		

channel through the main neck to increase its depth. In the course of the small rise in the latter part of 1934, noticeable developments of the cutoff channel occurred. It was noted in the early part of 1935 that the extreme lower end of the cut through the sandbar was not aligning itself in the most desirable manner, and the dustpan dredge Burgess was placed there in an effort to improve this alignment. The difficulty was of no particular moment so no anxiety resulted when the cut made by the Burgess failed to accomplish its purpose. Fairly high river stages, that is greater than bank-full, occurred for about three months in 1935, and in surveys following this high-water period, greater development was noted. It seemed, however, that the cutoff channel was still constricted near its upper end in the thick clay deposit, and no voluntary erosion of this clay occurred. In view of this, considerable dredging was done from time to time over the next three or four years when dredges could be spared from more urgent work, with the end in view of increasing the area of the channel through the noneroding material. Deterioration in the upstream end of the old bend channel began immediately after the cutoff started to develop, and this deterioration continued very rapidly. About 1938, after the cutoff had been functioning successfully for several years, minor recession of the left bank from about midway the length of the cutoff to the lower end took place. While this recession did not affect the functioning of the cutoff itself, it adversely affected alignment below the cutoff. Caving of the Mississippi shore at Belle Island across the river from the lower end of the cutoff began, and as this caving progressed, flow was deflected more sharply toward the Louisiana shore just above the head of Milliken Bend. The result of this deflection to the Louisiana shore caused bank caving there, and, in view of the fact that the controlling levee was not far distant from the shore, some apprehension arose. At the beginning, the caving of the Louisiana shore was not consequential, but it was easy to see that, with continued recession of the left bank at Belle Island, the attack would be directed more and more strongly against the right bank at the head of Milliken Bend. In order to attempt to remedy this situation, after much more or less profound thought on the matter, it was decided to make a dredge cut through the right-hand sandbar at the lower end of the cutoff. This cut was about two miles long and

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MAN-MADE CUTOFFS ON THE LOWER MISSISSIPPI RIVER, CONCEPTION, CO--ETC(U)
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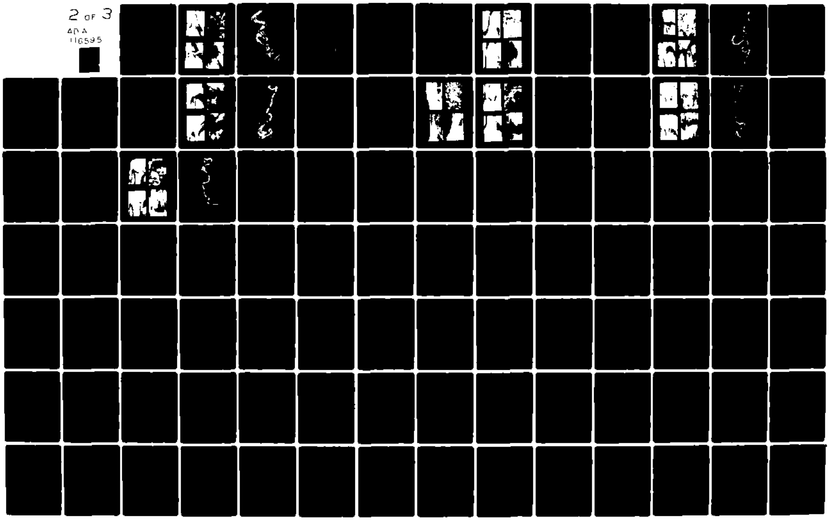


> to a depth of about 30 ft below standard low water, which, at this point, is 60 ft above sea level. The spoil was placed in the form of a dike parallel, and to the right of the dredge cut, at a distance of about 1500 ft.
>
> This work was not completed until the middle of January 1941. It appeared at first glance, and in view of the fairly rapid development of the new dredge cut, that the difficulty of alignment and directive below the foot of Willow Cutoff was overcome. Even at this time, though, there were several who had had long experience with the Mississippi River who felt that the new cut would not remain open and that a fairly high water stage would result in heavy deposits in this wide section. The 1942 survey shows that a great deposition of material took place, filling the new cut entirely and resulting in the return of the flow to a course along the left bank. It is difficult to find a specific explanation for action of this kind, but it has been observed through countless instances that the river objects to departing from its course along a shore line unless there is something to cause the deflection.... The last operations in the sandbar were another example of our failure to make use of the spoil from dredging. The cross section was being greatly increased in area by the dredging, and the area was probably already in excess of that required. Therefore, the spoil should have been returned to some location in the wetted area to compensate for the unneeded increase, which was being made.

Figure 33 provides an aerial view of the 1935 to 1974 cutoff and river development. Figures 34 and 35, respectively, show the historic development and the 1975 river in this reach as well as in the Marshall Point Reach.

6.15 Marshall Point Cutoff. The cutoff was opened in March 1934. The length of the original cut was 13,600 ft, and the distance around the bend was 7.3 miles, giving an initial slope of the cut 2.83 times greater than around the bend. This is one of the few cutoffs that developed with practically no additional dredging.

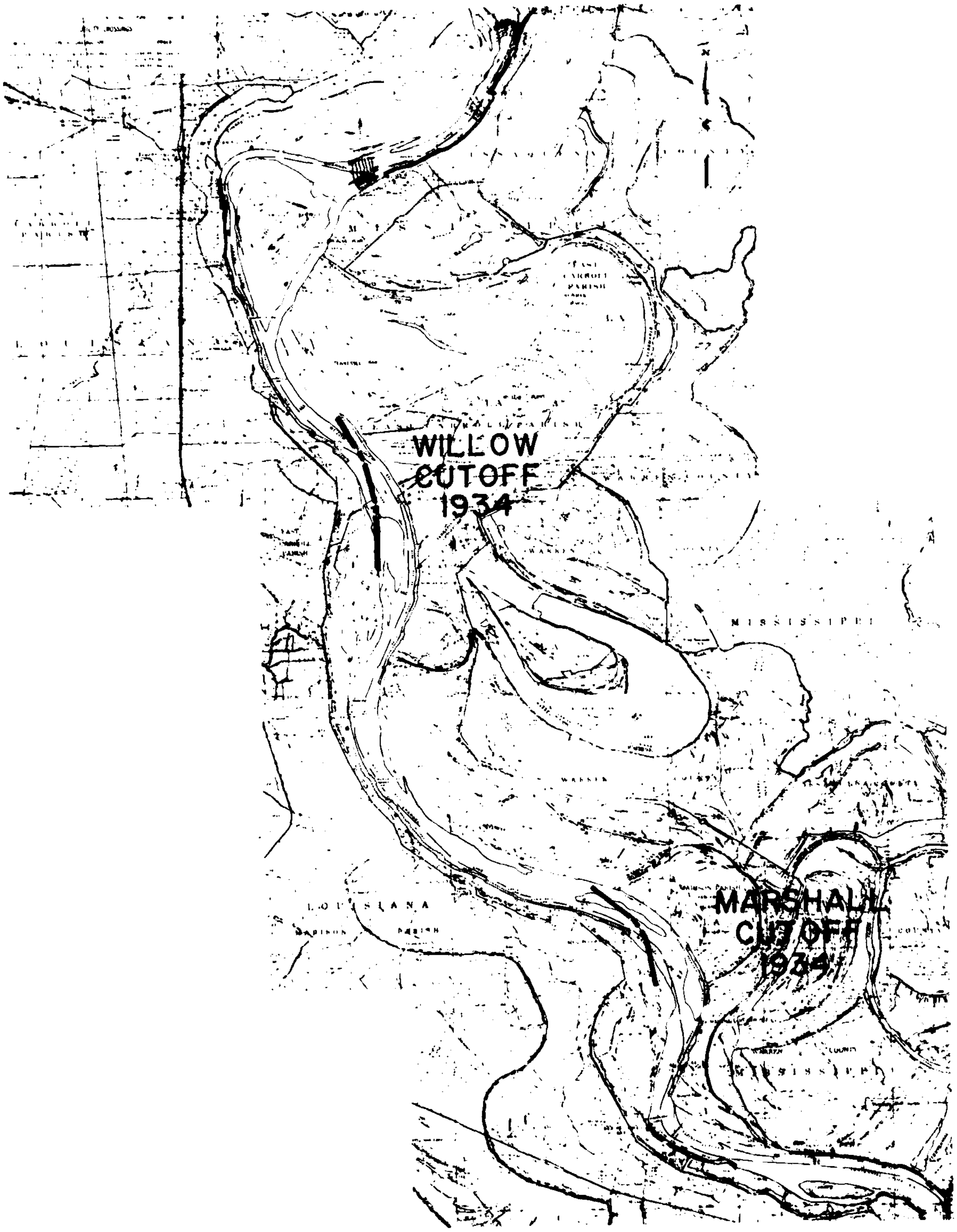
Stewart's comments on its development are:

> The cut of the land machines was to a depth of about 15 ft above standard low water. The dredge cut

AERIAL VIEWS OF WILLOW POINT CUTOFF

Figure 33

HISTORIC DEVELOPMENT OF THE WILLOW POINT AND
MARSHALL POINT REACHES



1975 MISSISSIPPI RIVER IN THE WILLOW POINT
AND MARSHALL POINT REACHES

Figure 35

was about 20 ft below standard low water. The soil in the upstream end was sandy and easily erodible. The downstream end was largely clay as might be expected in low marshy land. In view of these conditions, it was reasoned that a small pilot cut to shallow depth would suffice in the upper end and a deeper, wider cut would be necessary through the less erodible lower section; hence, the plan of operation developed which was used.

Developments proved that we were right in this instance. The pilot ditch was completed in late December 1933, and dredging in the lower section was completed in February 1934 [Table 15]. Almost immediately after the completion of the dredging, a fairly rapid rise occurred and flow through the pilot channel commenced. Development was rapid. The rise, which permitted flow through the new cut, was not of long duration. However, in the ensuing low water, flow through the new channel continued, and development continued at a most satisfactory rate. A very small amount of dredging was performed in the entrance to the cutoff on the right bank to remove an obstructing

Table 15

Marshall Point Cutoff Development

Date	Vicksburg Gage, ft	Flow in Cutoff % Low Water	Flow in Cutoff % Average	Flow in Cutoff % High Water	Amount Dredged cu yd	Dredged Accumulation cu yd
Initial cut opened 3/12/34					5,341,909	
4/17/34	33.6			10		
6/16/34	5.0	7			405,060	5,746,969
12/18/34	17.9		10			
4/16/35	48.2			22		
7/26/35	24.4		35			
11/5/35	5.1	60			355,261	6,102,230
1/31/36	20.0		48			
4/28/36	43.7			45		
6/29/36	5.3	73				
Opened for navigation Sep 1936						
2/17/37	55.1			47		
3/15/37	45.1			50		
6/23/37	22.8		81			
8/10/37	6.2	100				
1939		100		61		

> point which remained. After this point was removed, no further dredging or other steps toward the improvement of Marshall Point Cutoff were required. Within two or three years, it had become capable of carrying practically all of the discharge. The old river around the point deteriorated rapidly, beginning at the upper end and progressing downstream. A brief comparison of Worthington and Marshall Cutoffs may be interesting. You will remember that Worthington Cutoff was but little longer than Marshall. The difference in water-surface elevation on the upper and lower side of the two necks was but little different. The distance around the old river bends was little different. The character of material in Worthington Cutoff was similar to that found in the upper portion of Marshall Cutoff. Why, then, did Marshall Cutoff begin almost immediately to develop without assistance while Worthington remained obstinate for many years? Let us look at the conditions in the two cutoffs which were not similar. The entrance to Worthington Cutoff was, no doubt, too far downstream, resulting in a most difficult angle of entrance. The main draft of water was beginning to diverge from the left shore above the entrance to Worthington Cutoff. At Marshall Point, the entrance was in more favorable alignment. The principal flow was still impinging on the right bank. Therefore, when the channel was opened it was easier for the water to flow through it than to pass it by. Below the downstream end of Worthington Cutoff the river flowed through a divided channel. Neither of these channels was particularly efficient. Their depth was relatively shallow. Immediately below the downstream end of Marshall Cutoff was the deep bend around Brown's Point. This bend was a very efficient water carrier. These two points, being the only ones of consequence which differed in Worthington and Marshall Cutoffs, must hold the answer to the rapid development of the latter and the slow, unsatisfactory development of the former. Through the years since its opening, Marshall Point Cutoff has continued to maintain its alignment satisfactorily.

From the lower end of Cottonwood Bar above Willow Point Cutoff to the old mouth of the Yazoo River below Marshall Cutoff is about 26 miles today, but over the past 300 years[1] this reach averaged 56 miles. There were several natural length adjustments prior to man's attempts to control the river, thus a steeper than normal gradient. Figure 36 is a set

AERIAL VIEWS OF MARSHALL POINT CUTOFF

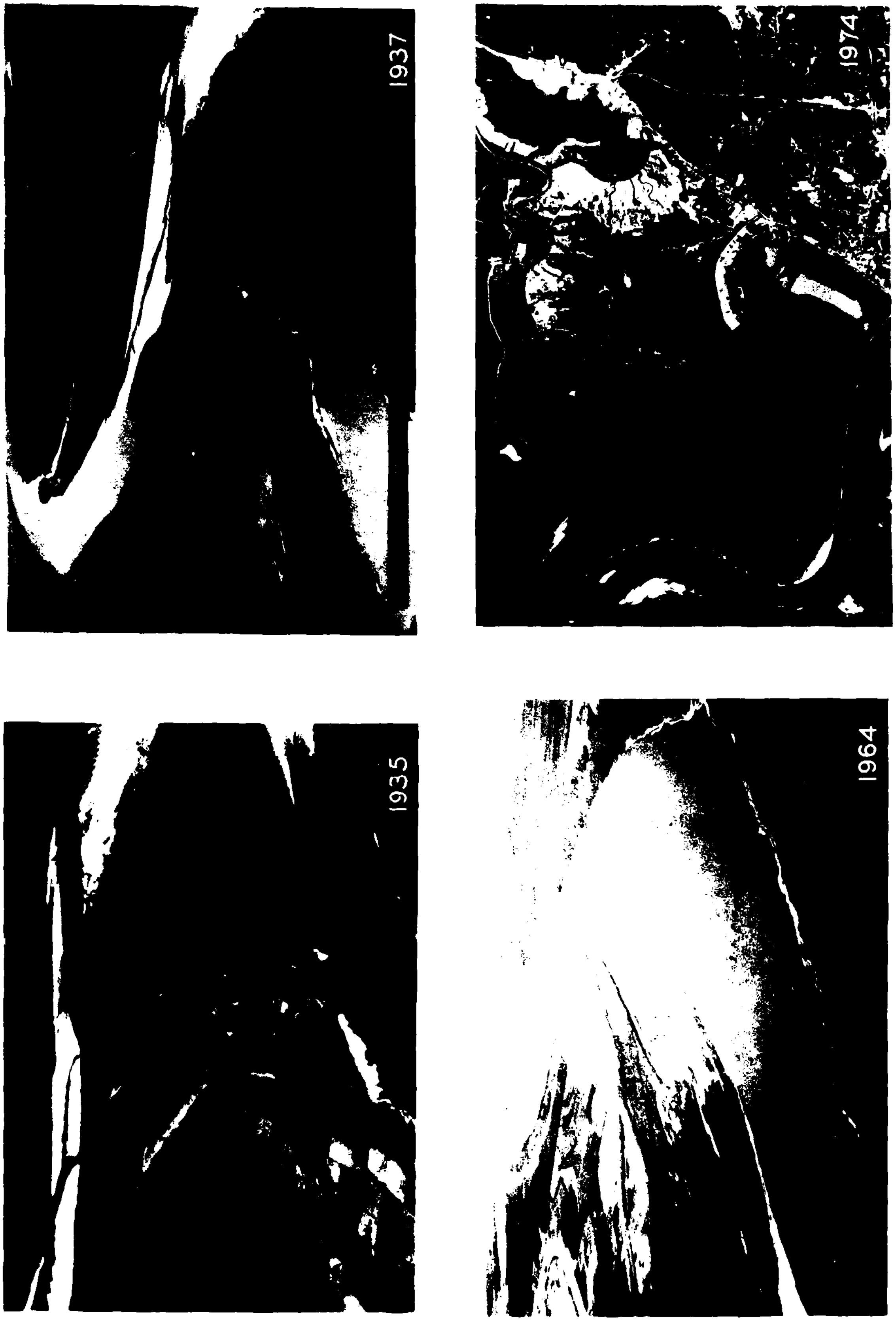


Figure 36

of aerial photographs showing the cutoff from 1935 to 1974.

6.16 Cutoffs Below Vicksburg. General Ferguson stated on 30 October 1937 in a communication to the Mississippi River Commission: "From Glasscock (Glasscock Cutoff below Natchez) to Vicksburg, the bed was not mobile. Buried snags, compacted sands, compacted gravel and silt, and gravel layers ranging from 1 to 6 ft thick...."

Three of the cutoffs below Vicksburg (Diamond, Giles, and Glasscock) experienced difficulty in development for a variety of reasons noted in the following sections. Recent borings and sediment samples do not agree with Ferguson's statement; he just happened to pick locations with unusual suballuvium, possibly the reason the river had not made a cutoff naturally.

6.17 Diamond Point Cutoff. Clemens describes its development as follows:

> Diamond Cut was the first to be constructed under the new program. It was opened 8 January 1933 [Table 16]. This cut is a short distance below Vicksburg. It returned the river to an old channel in Newton Bend, which it had abandoned in favor of a slightly shorter route through Palmyra Lake with a differential of some 10 miles in its favor.
>
> A number of interesting developments may be noted. First, as the cut deepened through natural scour, it was found that the bottom became remarkably uniform. This indicated that there must be something hard at this elevation. Check borings later developed that there was a layer of limestone rock about 50 ft below low water just below the limit of the borings taken prior to the dredging of the cut. However, 45- to 50-ft depth at low water is satisfactory but may somewhat retard the development of the cut.
>
> When the river left Newton Bend prior to the time the cut was opened, so much sand had been deposited that it has been a slow process working it out. Until 1935 it was not practicable to carry low-water navigation through this reach below the cut. During falling stages after the 1935 high water, considerable maintenance dredging was conducted, and an alternate navigation route through the cutoff was made possible during the 1935 low-water period. In the cutoff itself, the only dredging since its opening has been

Table 16

Diamond Point Cutoff Development

Date	Vicksburg Gage, ft	Flow in Cutoff % Low Water	Average	High Water	Amount Dredged cu yd	Dredged Accumulation cu yd
Initial cut opened 1/8/33					3,442,207	
1/19/33	38.3			11		
4/28/33	48.0			24		
6/12/33	48.7			32		
11/6/33	4.7	36			422,864	3,865,071
1/3/34	22.0		44			
4/16/34	34.4			40		
8/25/34	4.6	42			823,016	4,688,087
12/29/34	9.5	46				
4/12/35	48.2			43		
7/5/35	46.0			54		
8/30/35	17.5		55			
Opened for navigation Sep 1935						
11/8/35	5.0			47		
1/6/36	9.6	44				
5/5/36	42.0			64		
7/9/36	4.9	62				
9/11/36	-0.3	53				
2/22/37	55.5			45		
3/11/37	47.6			64		
5/11/37	28.9		66			
11/1/37	5.6	75				
12/20/37	-2.1	81			1,603,362	6,291,449
1938		86	83		2,632,933	8,924,382
1939				69	1,463,130	10,387,512
1940					2,852,659	13,240,171

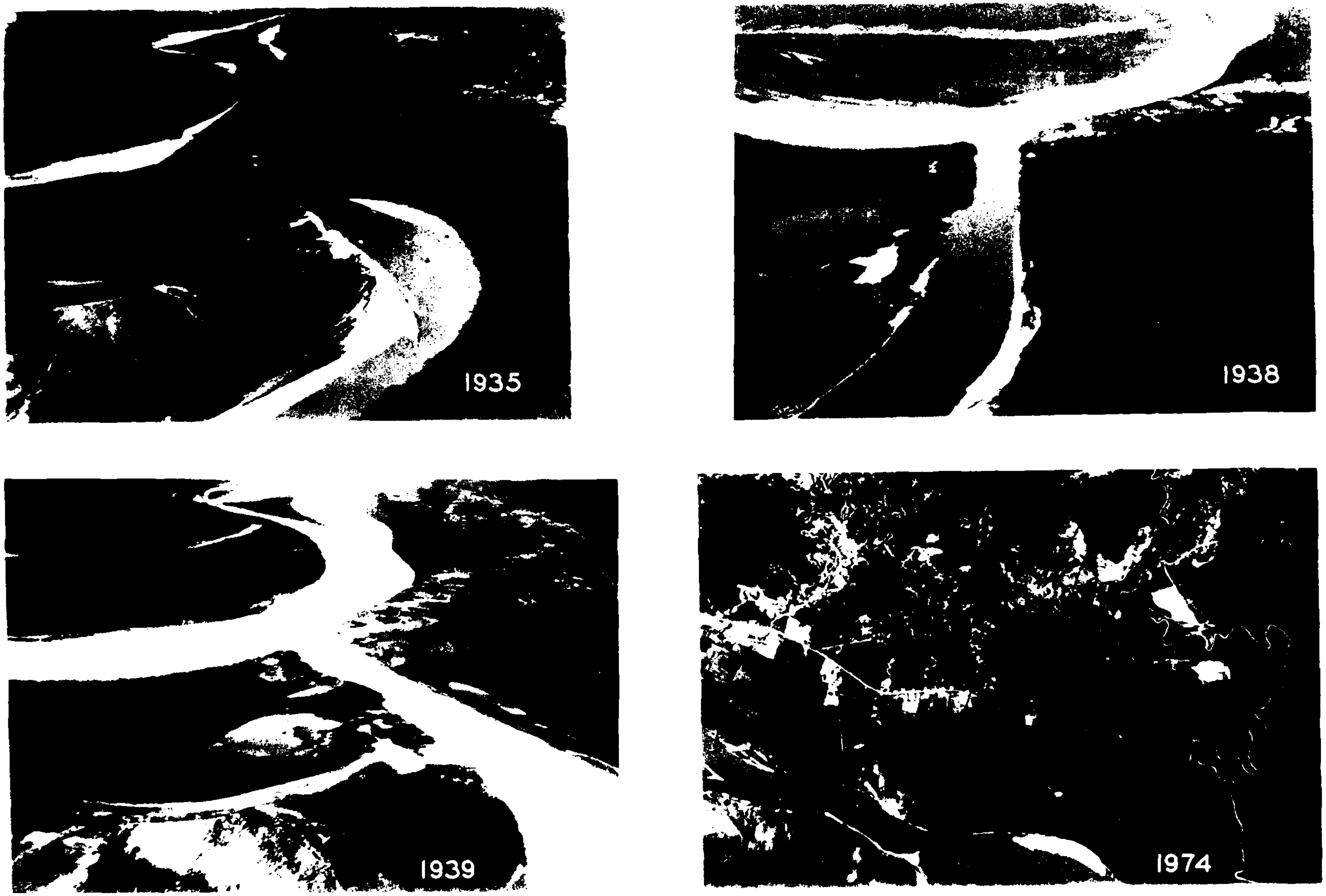
an improvement of the entrance in August and September 1934. About 800,000 cu yd of material was removed by a hydraulic dredge at that time. The cut has shown a gradual development and during the summer of 1935 carried slightly less than half the flow.

Figure 37 is a set of aerial photographs of the development of this reach for 1937 to 1974. Figures 38 and 39, respectively, show the historic development and the 1975 river in this reach as well as the Yucatan Cutoff Reach.

Work on this cut began in 1932 just two months after General Ferguson's arrival. The length of the original cut was 9200 ft, and the

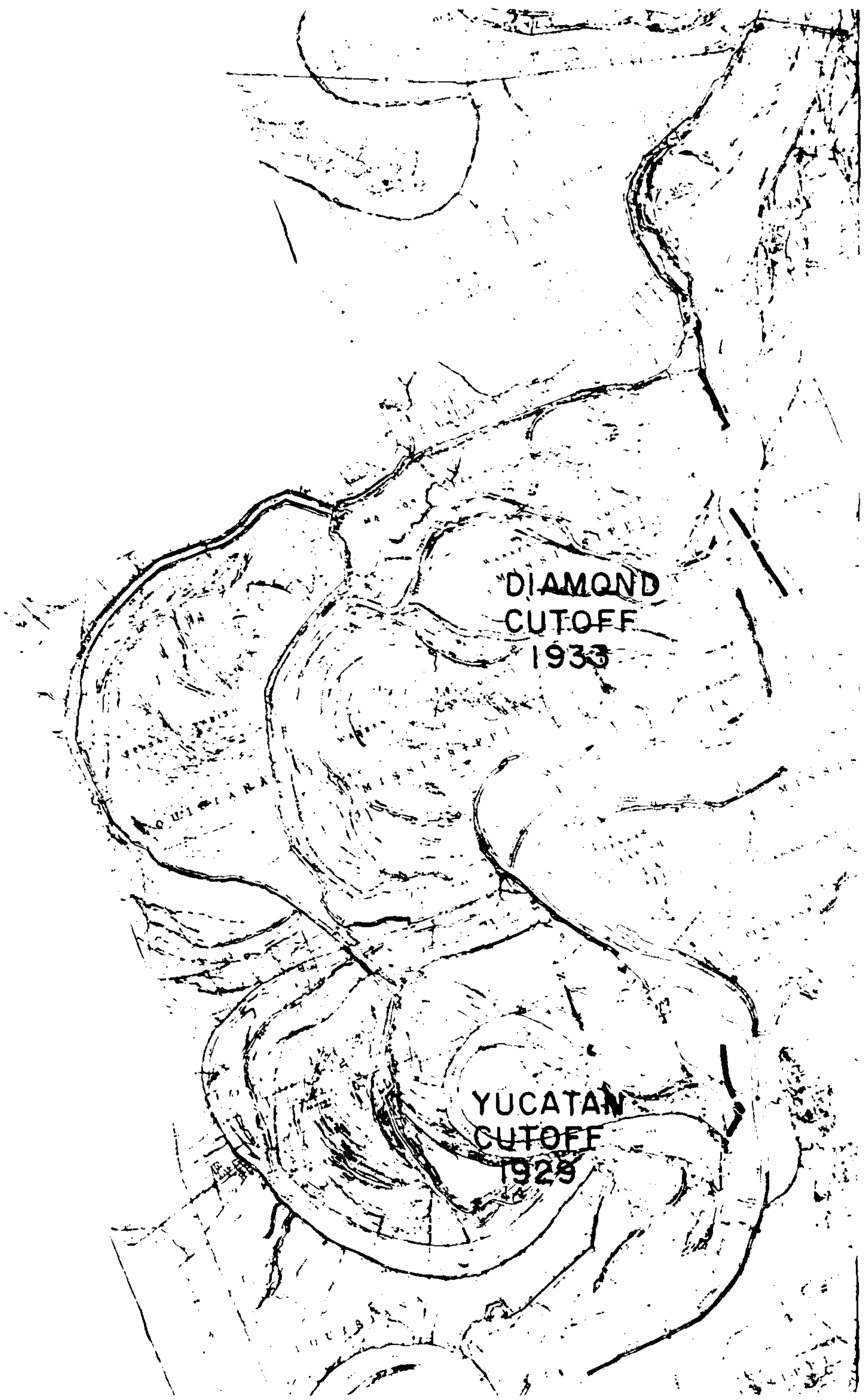
Figure 37

AERIAL VIEWS OF DIAMOND POINT CUTOFF



HISTORIC DEVELOPMENT OF THE DIAMOND POINT
AND YUCATAN REACHES

Figure 33



1975 MISSISSIPPI RIVER IN THE DIAMOND POINT AND YUCATAN REACHES

Figure 39

distance around the bend was 14.6 miles, which gave an initial slope of the cutoff of 8.4 times greater than around the bendway. The limestone mentioned by Clemens prevented continuous depth development so the width was increased to attain sufficient cross-section area. Because of this limestone ridge on the bed, plus limestone at about the same depth on both banks, a unique arrangement of pools and crossings developed that has persisted for 40 years. The position and elevation of pools, crossings, bars, and banks have not shown any changes in that period. The steeper slopes temporarily upset normal flows allowing Racetrack Towhead to develop upstream and throwing the alternate bars out of sequence.

6.18 Yucatan Cutoff. The Yucatan Cutoff was a natural cutoff which occurred in the fall of 1929 and resulted from caving of the left bank in Yucatan Bend into the channel of the Big Black River. It is mentioned here because it was the first cutoff allowed to occur in a period of 45 years and because it afforded an opportunity to collect data on the much controversial question of the effects upon the river regimen both upstream and downstream. The belief at that time was that a cutoff would develop at an alarming rate, depressing the stage above, raising it below and causing general disturbances both upstream and downstream. Such dire results did not occur. The river responds more slowly; these reactions are more evident in 1975 than they were at any time after the cutoff was opened.

While the channel of Big Black River afforded a relatively wide and deep initial cut, only 40 percent of the total flow of the river was carried by it at the end of two years. At the end of three years, it was carrying 60 percent. By 1939, 10 years after occurrence of the cutoff, it carried the entire low-water flow 90 percent of the bank-full flow. Some supplemental dredging was required to rectify the channel alignment upstream, and development of the cutoff was hastened by raising the sand-fills across the entrance to the old bend. Table 17 summarizes the data on the development of Yucatan Cutoff.

Experience at Yucatan and subsequent cutoffs definitely indicates that time is required to develop a cutoff and that corrective dredging is an essential requirement for its full and orderly development.

Table 17

Yucatan Cutoff Development

Date	Vicksburg Gage, ft	Flow in Cutoff % Low Water	Average	High Water	Amount Dredged cu yd	Dredged Accumulation cu yd
Natural cutoff fall 1929						
5/14/31	24.5		33			
1/13/32	38.6			41		
7/27/32	24.0		71			
Opened for navigation Jul 1932						
12/20/32	13.3		77			
1/27/33	36.7			64		
5/10/33	47.0			75		
1/11/34	13.9		86			
2/27/34	7.4	94				
4/17/34	33.6			95	239,600	
4/29/36	42.2			87		
1/7/37	45.2			70		
2/8/37	52.5			59		
6/2/37	26.6		99			
8/31/37	3.8	100				
1938					1,074,100	1,313,700
1939			100	90		

Concerning this cutoff's development, Clemens comments:

> Yucatan Cutoff was made by the river itself during the fall of 1929. It is unusual in that it resulted from low-water caving and accidentally formed an alignment that was favorable for improved river conditions in the reach of the river in which it is located. In fact, we might say it was the classic illustration which helped to point the way and allay fears as to the terrible catastrophes that would inevitably result from cutoffs. Its development has progressed gradually without requiring any dredging. The 1935 low-water season finds the old channel closed off up to 25 or 30 ft above low water, with all the flow below this stage through the cutoff. No serious maintenance, dredging problems have developed either below or above the cut. The cutoff is extremely deep, with relatively low velocities at low water.

The cutoff through the Black River channel was 9000 ft, and the distance around the bendway was 12.8 miles, making the initial slope

through the cutoff 7.5 times steeper than the bendway. The cutoff developed in a rather orderly fashion, but the reach has become very unstable and troublesome in recent years. Figure 40 is a set of aerial photographs showing the development of this reach from 1935 to 1974.

The river from below Racetrack Towhead to below Yucatan Cutoff is about 20 miles long today, but over the previous 200 years this reach averaged 48 miles in length. The valley slope is much flatter here than anywhere else between the Arkansas and Red Rivers except in the Kentucky Bar-Mayersville Reach. This could be partially responsible for the reach upstream and downstream reacting so slowly to the cutoffs (Yucatan and Diamond). Today's river in this reach is very unstable.

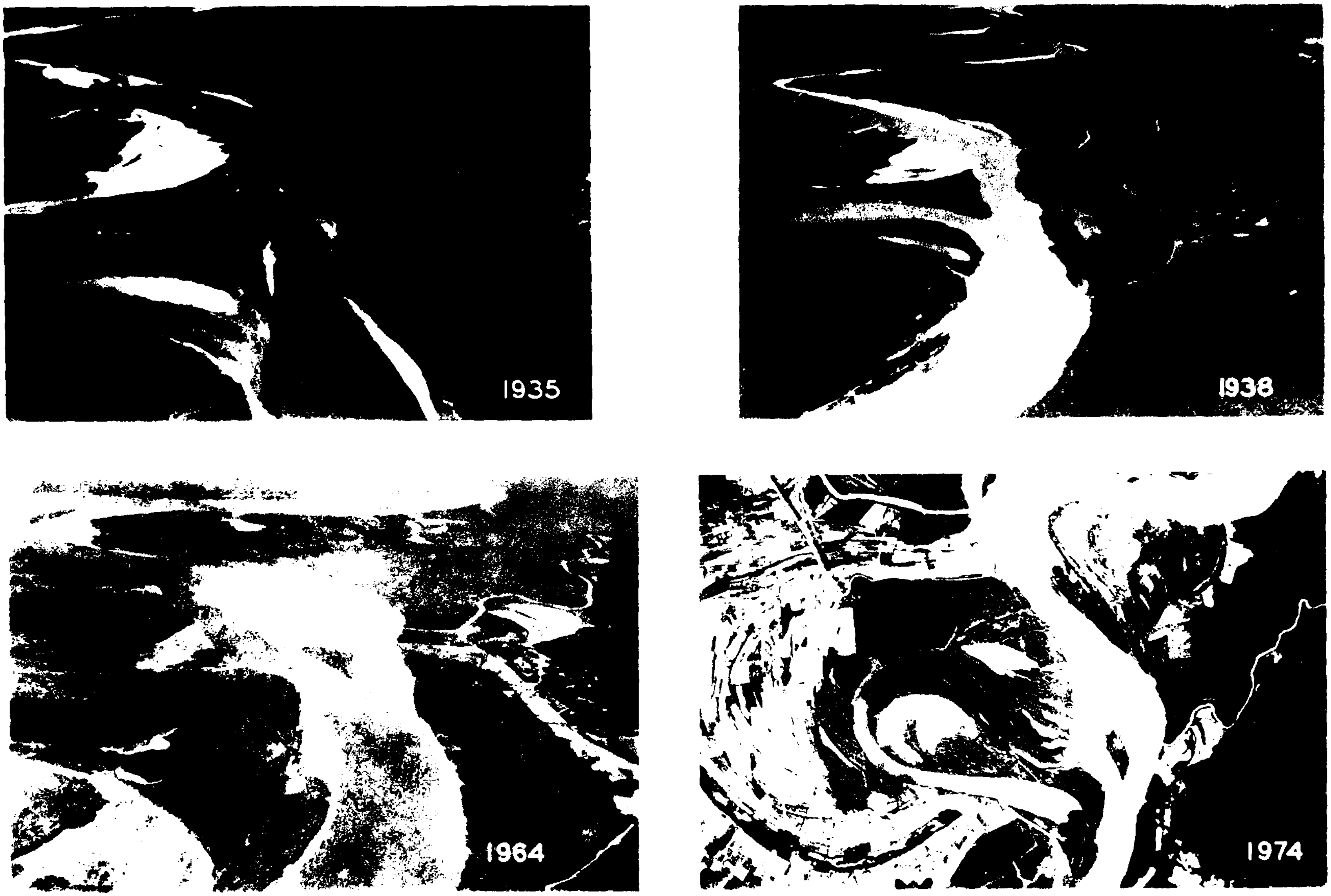
6.19 Rodney Cutoff. Rather complete foundation investigations were conducted along the selected alignment and into the bends above and below the site of the Rodney Cutoff prior to initiation of work. The original cut was 13,000 ft long, and the distance around the bend was 9.9 miles, making the initial slope through the cut 4 times as steep as the bendway.

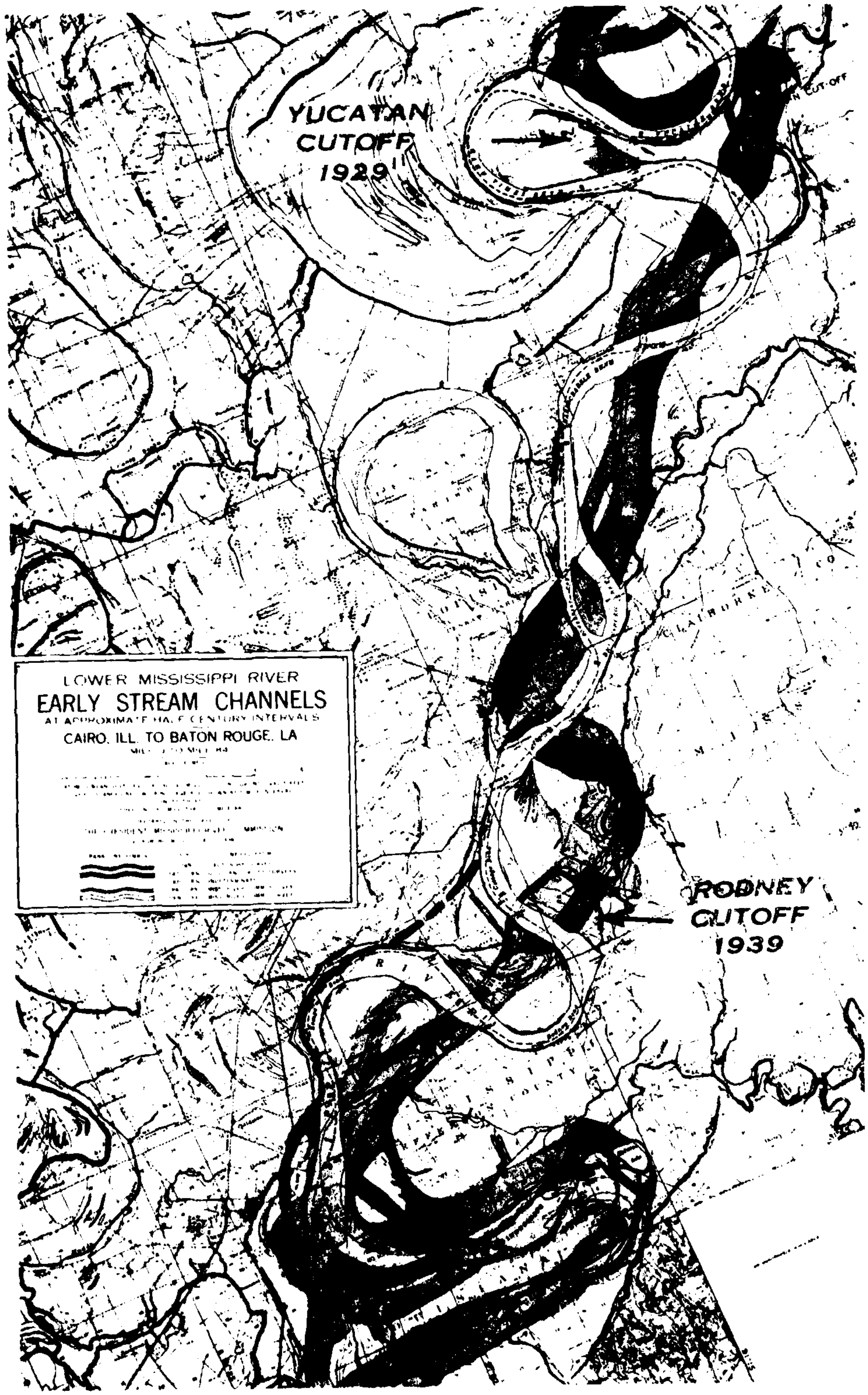
Clemens describes this cutoff as follows:

> Below St. Joseph, La., the alignment of the river has been such that a cutoff was desirable at Rodney Point, and it was begun during the latter part of the 1935 high water. A pilot dredge cut was started similar to that made at Sarah Point. Work was suspended during the 1935 low water but will be resumed before the 1936 high water, and it is planned to have the cut completed for the 1936 high water.

This cut developed rapidly the first two years, probably because of the readily erodible foundation material and the magnitude and duration of the 1937 flood (Table 18). However, this same easily erodible material allowed the river to develop middle bars with associated navigation problems. Several more years of excessive dredging were necessary in order to maintain navigation through the cut. The alluvium in this reach tends to be very sandy with an unusual amount of coarse sand and gravel, possibly a result of the river migrating along the hill line during the past several hundred years (Figure 41). This section could have swept the coarse sediments from the alluvial fan adjacent to the

AERIAL VIEWS OF YUCATAN CUTOFF





HISTORIC DEVELOPMENT OF THE RODNEY REACH

Figure 31

Table 18

Rodney Cutoff Development

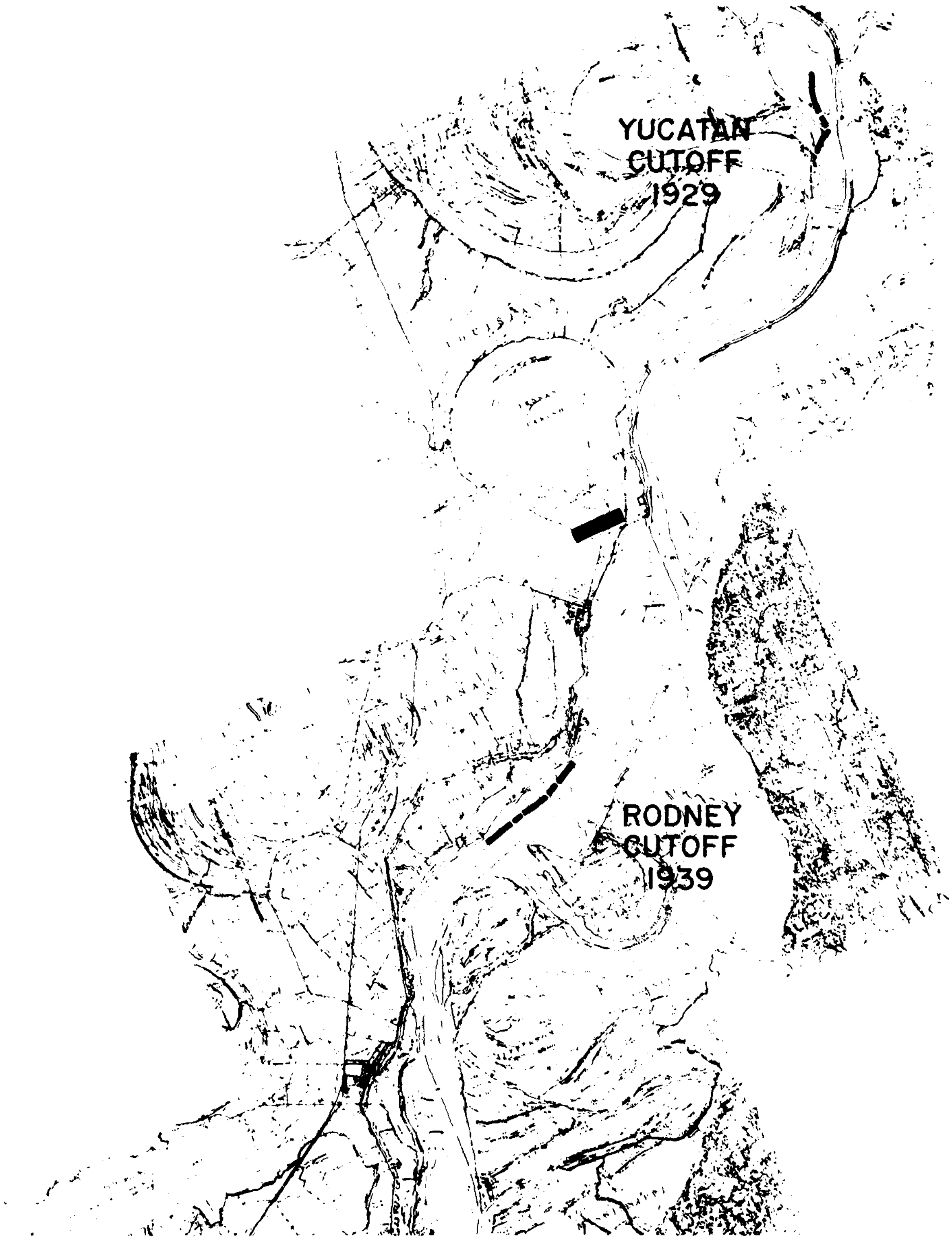
Date	St. Joseph Gage, ft	Flow in Cutoff % Low Water	Flow in Cutoff % Average	Flow in Cutoff % High Water	Amount Dredged cu yd	Dredged Accumulation cu yd
Initial cut opened 2/29/36					2,641,559	
3/18/36	31.8		8			
5/1/36	46.1			8		
7/24/36	4.8	15			5,635,845	8,277,404
Opened for navigation Sep 1936						
2/25/37	53.7			10		
5/24/37	36.0			34		
8/6/37	4.4	50				
10/16/37	-3.1	74			2,580,5[illegible]	10,[illegible]
1938		78	92		474,[illegible]	[illegible]
1939				54	1,268,[illegible]	[illegible]
1940					1,275,91[illegible]	[illegible]
1941					8,657,[illegible]	[illegible]
1942					1,534,[illegible]	[illegible]

hills into the delta. The thalweg profile is steep and the gravel pro-file in this reach is extremely high, possibly the result of the [illegible] meandering action. Today's river is very unstable in this reach (Figure 42).

Figures 8 through 12 of L. G. Robbins' report[15] on Mississippi [illegible] sediments show gravel and sand formations on the middle bar at Rodney Cutoff. Figure 43 provides a set of photographs of the waves and dunes of gravel in Gilliam Chute just downstream of Rodney in Spithead Towhead (Figure 41). Figure 44 presents aerial views of Rodney Cutoff from 19[illegible] to 1974.

6.20 Giles Cutoff. According to Clemens, this cutoff developed as follows:

> Giles Cut, a short distance above Natchez, is another place where the river was somewhat contrary. To look at the map, it would appear that one or two deep furrows with a plow across the point would probably result in it cutting off. In fact, a cut was feared at this location, and both revetment and a dike



1975 MISSISSIPPI RIVER IN THE RODNEY REACH

Figure 42

GRAVEL FORMATIONS IN GILLIAM CHUTE

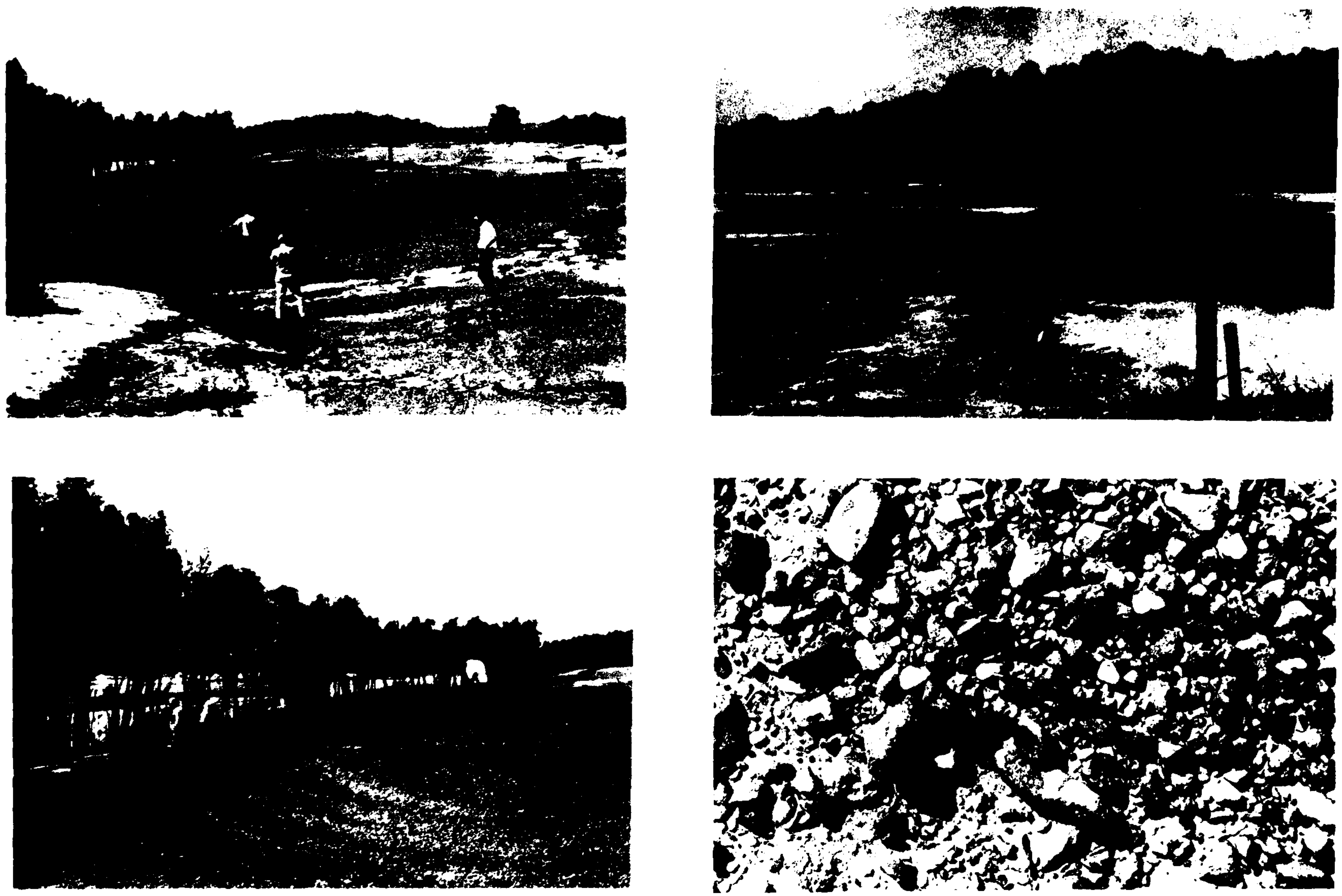
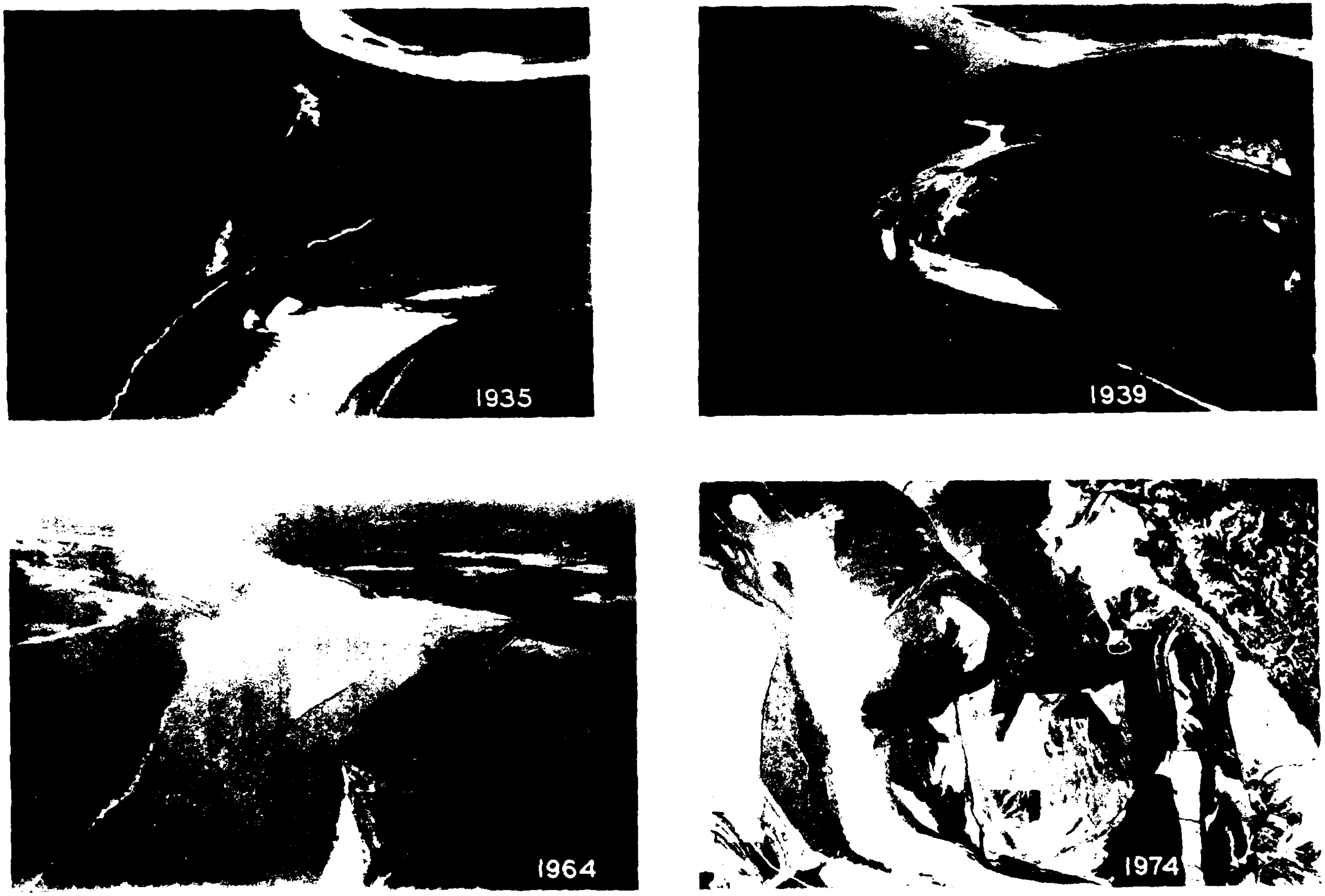


Figure 43

AERIAL VIEWS OF RODNEY CUTOFF



> had been built to prevent it. A shallow dragline cut across the point was begun 24 March 1933, and completed 22 May 1933, about 800,000 cu yd being removed. To facilitate its development, the cut was enlarged by dredging at the same time, and about 1,200,000 cu yd of additional material was removed. The 1933 high water broke through, but when the water lowered, the bed did not scour to form a low-water channel. Cypress forests were buried in the bottom of the cut, and they were cemented into an effective dam by Mississippi Valley hard blue mud. During the summer and fall of 1933, about 2,000,000 cu yd more of material were removed by hydraulic dredges. The 1934 high water was not sufficient to dislodge this natural dam, and during the low-water season, no flow took place in the channel. During the 1934 season, 7,000,000 cu yd more were cut out by 27-in. hydraulic dredges, and on 10 October 1934, low-water flow passed through the cut. A gradual development has followed, and 1935 low water finds about 40 percent of the total flow through the cut without additional dredging. The hard banks are still very resistant, and the cut is rather narrow for navigation but is used as an alternate route. After another high-water period, it may develop to suitable size for all stage navigation.

Table 19 presents pertinent data on the Giles Cutoff development.

The original cut of 10,000 ft was made adjacent to the hills immediately above Natchez. The distance around the bendway was 14.7 miles, giving the original cut a 7.76 times greater slope than the bendway.

Today (1975) the river is extremely narrow in this reach and has never migrated from the original cut made 43 years ago. It has widened slightly but averages only 2200 ft in width today. Interestingly, in spite of the confined straight channel, the river has reestablished a sequence of pools and crossings exactly as it would if allowed to meander and in the same relationship as the form of the 1932 river.

Experience with the Giles Cutoff indicates that anticipating a river's reaction without knowledge of the alluviums and suballuvium is pure guesswork. Today, when we are faced with a need to reestablish flood control and navigation, a knowledge of the sediments in a reach under consideration is imperative prior to final decisions.

Measurements of the channel conditions during the 1945 and the 1950

Table 19

Giles Cutoff Development

Date	Natchez Gage, ft	Flow in Cutoff % Low Water	Average	High Water	Amount Dredged cu yd	Dredged Accumulation cu yd
Initial cut opened 5/25/33					1,859,010	
6/11/33	50.3			3	5,341,908	7,200,918
10/8/34	6.3	10			5,468,517	12,669,435
12/14/34	21.7		12			
Opened for navigation Jan 1935						
4/23/35	50.3			20		
8/17/35	17.9		44			
10/12/35	5.8	50				
2/25/36	20.1		40			
5/2/36	46.1			33		
11/19/36	20.3		46			
12/5/36	5.5	60			1,014,622	13,684,107
1/31/37	13.9		50			
2/25/37	58.0			37		
3/13/37	51.4			42		
7/7/37	22.5		57			
10/1/37	4.3	81				
10/18/37	5.8	76			4,689,852	18,374,059
1938		100	94		1,553,819	19,927,878
1959				58	1,163,187	21,091,065

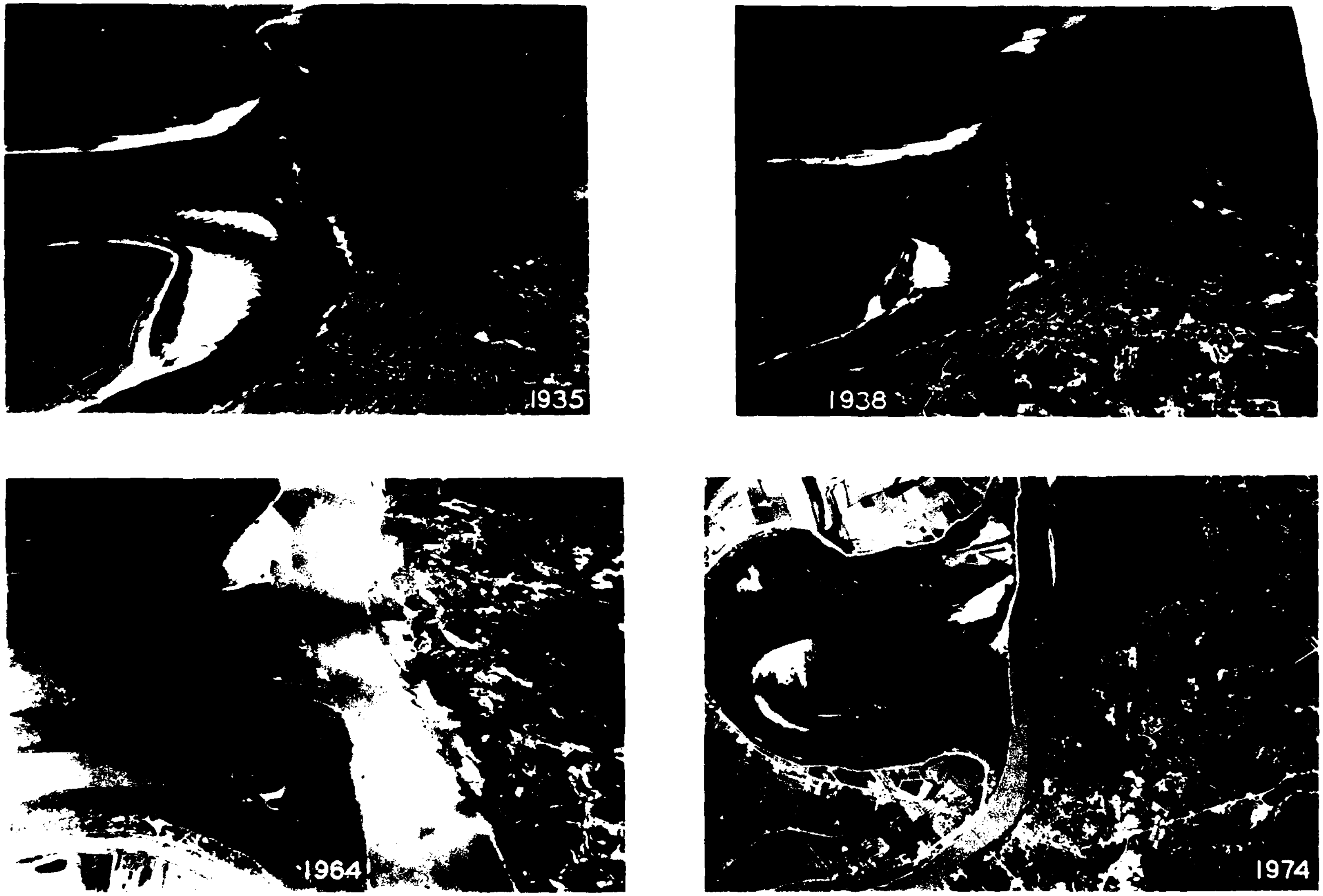
floods indicate approximately 300,000 cfs of flow in the old bendway. This is partially the reason for the observed lower flow lines in those floods in this reach as compared to the 1973 flood. Other cutoff channels have probably reacted similarly.

Figure 45 is a set of aerial photographs of the Giles Cutoff from 1935 to 1974. Figures 46 and 47, respectively, show the historic development and the 1975 river in this reach.

6.21 Glasscock Cutoff. In describing this cutoff Clemens states:

> Glasscock Point is located about 20 miles below Natchez. The cut across this point is about 4 miles long and has been the most difficult to develop. Scour must occur throughout its entire length before full development is obtained. The middle section of the cut is across an old lake bed, which is so soft it has slid in and closed off all channels cut

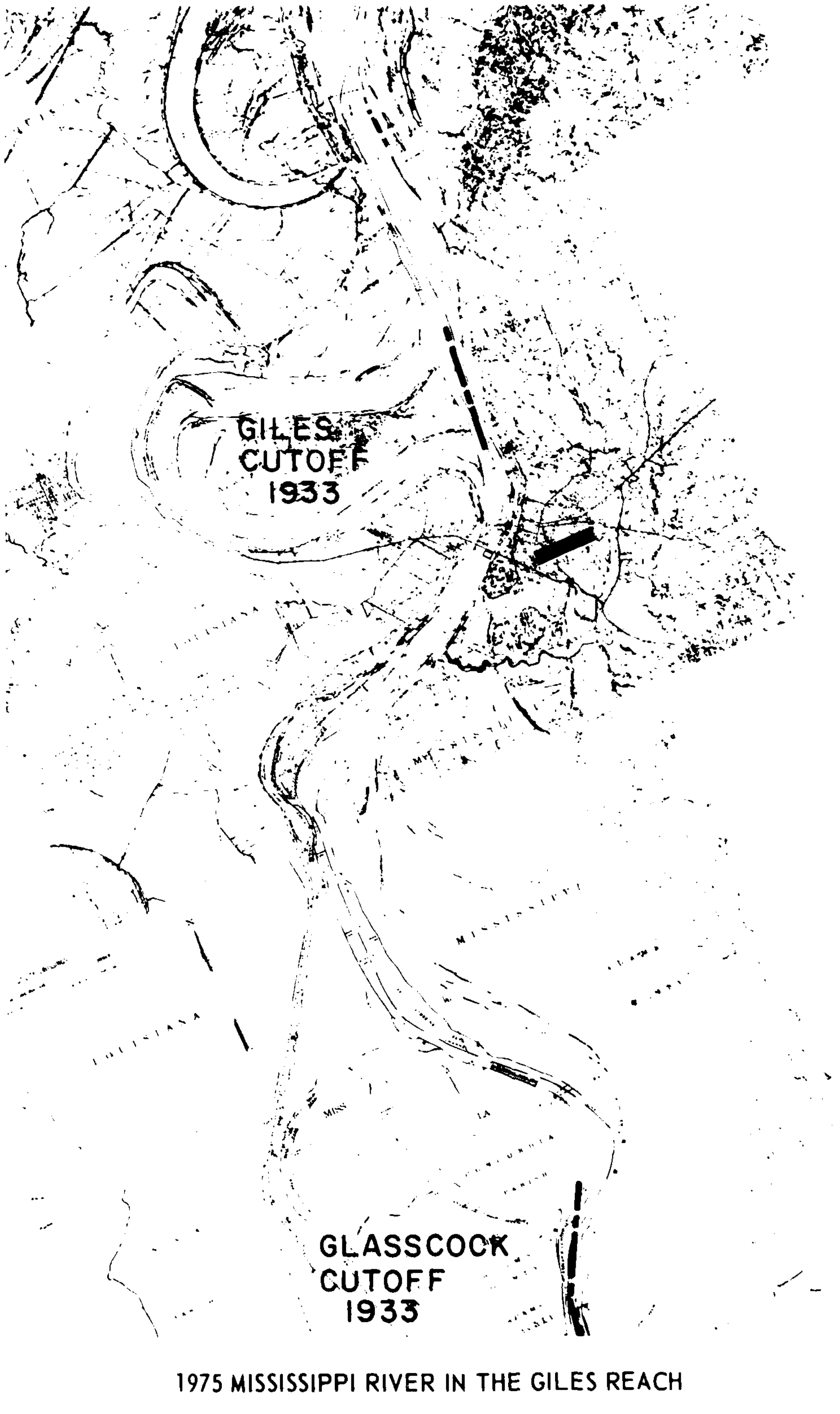
AERIAL VIEWS OF GILES CUTOFF



Figure

HISTORIC DEVELOPMENT OF THE GILES REACH

Figure 36



1975 MISSISSIPPI RIVER IN THE GILES REACH

Figure 47

> across it at low water; it is also greasy and slippery and thus effectively resists erosion at high water. There was only a small flow through the cut during the 1935 low-water period and this was insufficient for navigation purposes.
>
> Similar to the procedure at Giles Cut, the initial construction operation was a shallow dragline cut. This involved about 1,000,000 cu yd of excavation, which was removed between 21 January 1933, and 26 March 1933. At the same time, but extending into April 1933, hydraulic dredges moved an additional 1,800,000 cu yd. After the 1933 high water came up and receded, the low-water channel did not open through. During summer and fall of 1933, a hydraulic dredge moved 3,500,000 cu yd. As the 1934 water came up, it soon became apparent that this would not scour out a channel. Consequently, work was begun during this high-flow period to open up a low-water cut. These operations extended through the low-water season up to January 1935 although suspended during the extreme low-flow months, and a total of 3,800,000 cu yd was removed. The 1935 high water did a large amount of scouring, but two or three dams were left in the channel. As 1935 low water came on, the channel held up fairly well, but at extreme low stages the lake section closed in again and almost stopped the flow.... Additional dreding is being conducted to remove the dams in the cut and further enlarge the lower end in the hope that the next high water may be sufficient to get a satisfactory channel started.

Table 20 summarizes the data on the development of Glasscock Cutoff. The original cut was 20,800 ft long, and the bendway distance was 15.6 miles, making the original cut have a slope 3.96 times greater than the bendway. The development of this cutoff was hindered by the above-mentioned soil problems plus the gentle river slope of only 0.2 ft/mile in this reach. Continuous dredging was necessary for 10 years before the cutoff became self-maintaining. Today (1975) the average top bank width in the cutoff is only 2500 ft. It has almost the same location and alignment as the original cut and like Giles Cutoff has reestablished the normal sequence of pools and crossings.

Figure 48 is a set of aerial photographs of the development of this reach from 1935 to 1974. Figures 49 and 50, respectively, present the

historic development and the 1975 river in this reach.

Table 20

Glasscock Cutoff Development

Date	Natchez Gage, ft	Flow in Cutoff % Low Water	Average	High Water	Amount Dredged cu yd	Dredged Accumulation cu yd
Initial cut opened 3/26/33					3,442,707	
5/3/33	49.6			2	8,813,679	12,256,386
1/27/35	30.7		5			
4/24/35	50.3			13	2,984,618	15,241,004
8/12/35	21.6		10			
10/11/35	5.9	1			2,750,452	17,991,456
1/31/35	25.0		10			
5/4/36	45.8			14		
7/22/36	6.0	12			1,706,199	19,697,655
11/18/36	20.3		13			
2/23/37	58.0			21		
3/15/37	49.5			21		
7/6/37	22.3		30			
Opened for navigation Sep 1937						
12/13/37	5.9	40				
12/20/37	3.2	42			5,388,543	25,086,198
1938		75	71	42	5,577,812	80,664,010
1939					4,858,116	35,522,126
1941					542,851	36,064,977
1942					2,008,470	38,073,447

AERIAL VIEWS OF GLASSCOCK CUTOFF

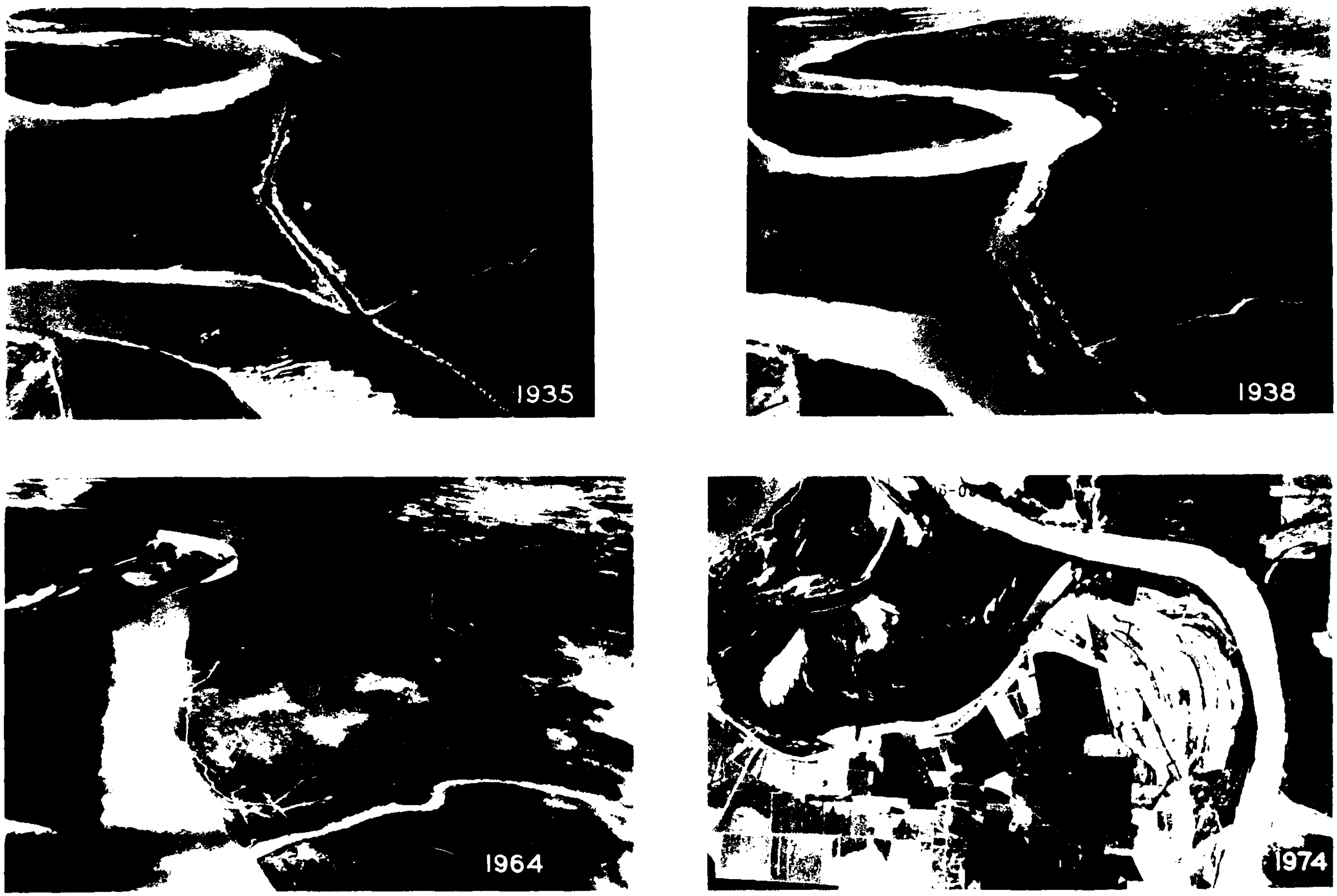
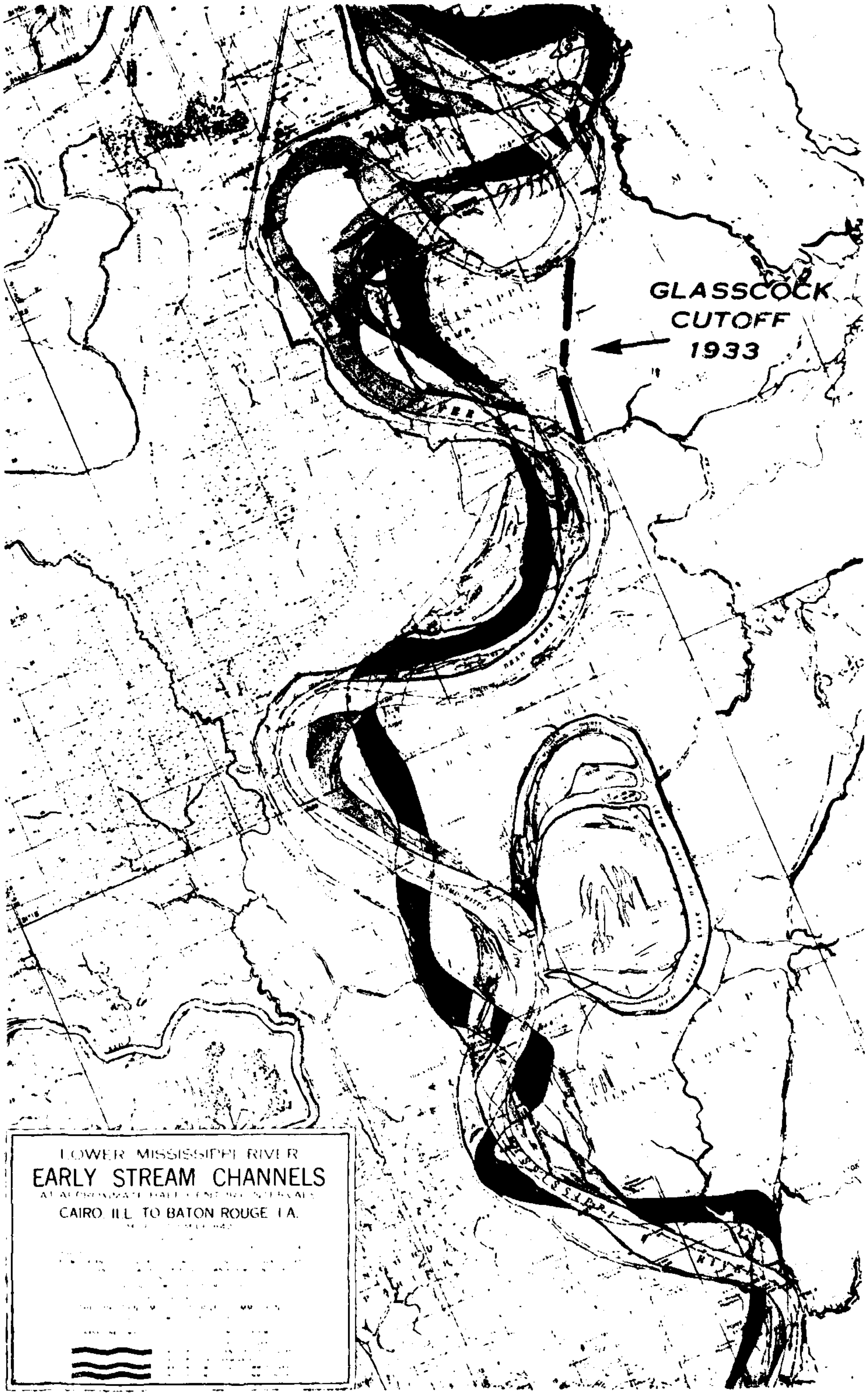
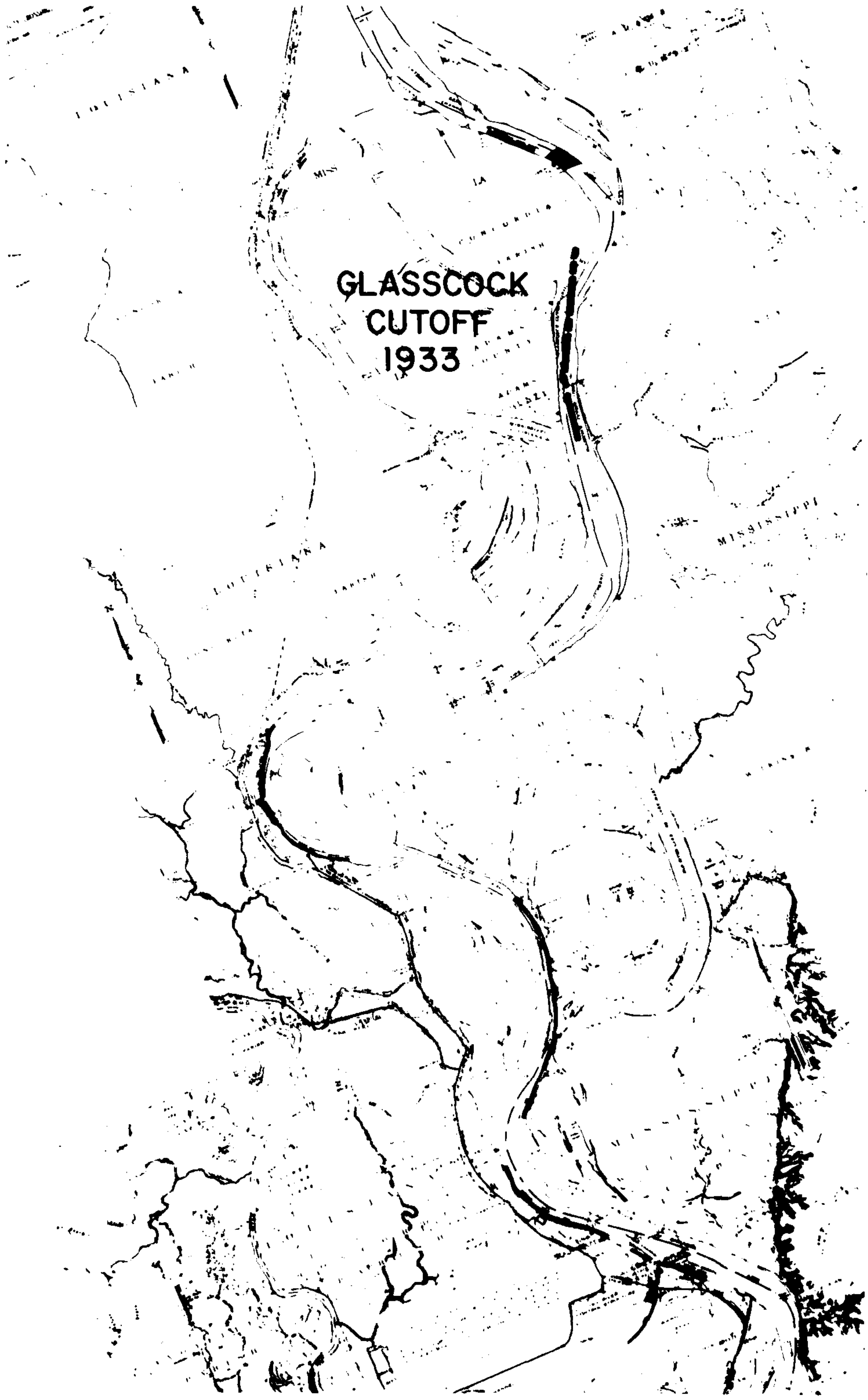


Figure 4



HISTORIC DEVELOPMENT OF THE GLASSCOCK REACH

Figure 49



1975 MISSISSIPPI RIVER IN THE GLASSCOCK REACH

Figure 50

SECTION 7. CONSTRUCTION ACTIVITIES ON THE RIVER AFTER CUTOFFS

The postcutoff period was also the period of a concentrated effort to gain better flood control and navigation. The amount and type of construction during this period are not necessarily just the result of the river's reactions to the cutoffs but could also be the result of continued efforts to establish a new and different alignment for the river.

Alignment and stabilization of the cutoffs were initially done with the hope of making the high- and low-water centroids of flow coincident. It was felt that this alignment would reduce the maintenance problems and be relatively permanent, needing very few training structures and minimal bank protection. Unfortunately, this approach to stabilization will not succeed on an alluvial river with a movable bed. In alluvial rivers, the low, high, and all intermediate flows tend to seek a geometric shape related to that particular flow.

Riverflow varies throughout the year and is cyclic between wet and dry periods; therefore, the river is constantly attempting to adjust its geometry to fit the existing flow. No single shape would be optimum because the movement of sediments is not proportional to the movement of water through the system even though it is related. The geometry that would probably have the least maintenance would be the geometry associated with top bank flows.

Some flood control projects have had compensating effects; e.g., levees forced more waters into the channel and created a need for larger geometric patterns, while cutoffs and the low/high-water realignment program attempted to make longer radius bends and steeper slopes and thus build a geometry more compatible with higher flows.

The movement of water and suspended sediment in a river with the characteristics of the Lower Mississippi does not cause many problems that cannot be accommodated by a channel of sufficient size even under conditions of an inconsistent alignment. The problems arise from the movement or lack of movement of the bed sediments. The bed sediment transport might be minimized but can never be eliminated. Proper control is accomplished by a plan and profile geometry that moves the

sediment downstream as uniformly as possible and provides interim storage between times of high flow.

Since 1811, the Lower Mississippi River has attempted to adjust its geometry to the changing conditions imposed by both nature and man. The stabilization program following the construction of the cutoffs has locked the river into a transition state that varies from reach to reach. It is not the intent of this section to indicate or to analyze the needed hydraulic-geometric pattern but rather to illustrate the nature of the work accomplished in an attempt to hold the postcutoff shape of the river.

Table 21 provides a comparison of the Greenville Reach before and after cutoffs, and Figure 20 portrays the changes in alignment. This reach is not typical but is an extreme example of an attempt to change a river's characteristics. It is interesting to note that in spite of all the work concentrated in this reach, the river is attempting to maintain a natural hydraulic-geometric condition.

Table 21

Greenville Reach Construction and Response

Greenville Reach Before and After Cutoff		
	1933	1975
Number of crossings	8	8
Average minimum depth of crossings below low water	21 ft	22 ft
Range of depths in crossings below low water	14-24 ft	3-36 ft
Average deepest part of pool below low water	66 ft	65 ft
Construction Required to Maintain Navigation		
	Prior to 1933	1934-1974
Number of times crossings were dredged to maintain navigation	0	135
Length of revetment to hold channel	76,350 ft	137,050 ft
Length of dikes in reach	3,377 ft	61,596 ft
Length of river from upper end of construction to lower end	51 miles	24 miles

C. L. Hall, commenting on Matthes' 1947 paper,[7] states:

> A judgment on the utility of the plans (on cutoffs) therefore requires answers to three questions:
>
> (1) How much are costs of channel maintenance increased by cutoffs?
> (2) What flood control works are made unnecessary by the plan?
> (3) To what extent is levee maintenance reduced?
>
> There is nothing in this paper[7] to show that these questions have ever been propounded. There is certainly no sign of an answer to them.

The above questions still have not been answered (1977) and probably never will be conclusively resolved.

7.01 Levee Construction. Levee construction began in the early 1700's, and levee development has been largely the result of practical experience. The essential conditions governing levee construction are: (a) a height adequate to prevent overtopping; (b) a base wide enough for protection against destructive foundation seepage; and (c) a cross section sufficiently massive for security against dangerous seepage through the structure itself.

As the levee lines were extended and as more and more of the numerous outlets were closed, the increased confinement of flow required higher levees. Figure 5 shows the increase in high flow stages and the increase in levee heights in relation to the Natchez, Mississippi, discharge gage. Table 22 logs the average increase in length and height of levees in the Lower Mississippi Valley.

No appreciable length of levee has been added since 1931, but recent changes in flood heights may require up to an additional 6-ft increase in height in some areas, from the Arkansas River south toward the Gulf. Levees have been set back at numerous places as the natural meandering tendencies of the river continued. Many levees, particularly in the New Orleans District, are constructed very close to the river's top bank, with residential and commercial construction at the landward toe of the levee. Changes in river characteristics induced by flood control measures are moving larger quantities of coarser bed sediments farther downstream at an increasing rate. This action will result in bar

Table 22

History of Levee Construction

Year	Average Levee Heights, ft	Levee Construction, miles
1719	3.0	20
1735	4.0	42
1880	7.0	991
1890	8.0	1239
1905	13.0	1439
1910	14.5	1500
1920	20.0	1547
1927	24.0	1582
1931	30.0	1830

building and increased bank caving plus channel filling in the lower reaches. The results of this are increased navigation and flood problems, plus the need to move levees away from the riverbank.

7.02 Dike Construction. The design and location of dike fields has been very inconsistent over the past decades. The need for dikes seems to have been more for the correction of a local problem than for the development of an alignment designed for the movement of the bed sediments.

A dike can be used to close off a secondary channel, direct flows, or narrow the main channel. In order to perform as efficiently as possible, a dike should work with the natural flow lines of the river and not oppose the normal pool, crossing, and bar-building tendencies. The best results are attained if the dike field is designed for each location using the river's forces and reactions to accomplish the desired results. This design can be achieved by the following procedure:

- a. Use stage or multiple year construction; i.e., do not force too great a change on the river at one time, thus allowing the channel to make an orderly adjustment.
- b. Work with the existing and desired flow lines.
- c. Slope the crown of the dike similar to a natural bank or bar slope. This will minimize scour and aid in the accretion of sediment behind the dike.
- d. Shape the dike field like a natural bar for a particular location.

e. Use combinations of materials to accomplish the final results in the most feasible manner.

Characteristics of rivers vary from basin to basin and from reach to reach in the same river. Dike design and location also has been widely varied; therefore, it is impossible to compare applications and results without considering such things as sediments, alignments, and variations in flows. Currently, the most successful method of training a river is with the use of properly designed and properly located dikes.

7.03 Revetment Construction. The quantity of bank protection in the lower Mississippi River has varied considerably since 1880 (Figure 51). The period from 1945 to 1965 was the most active. Unfortunately, this is the period when the river was trying to adjust to the forced alignment of a series of cutoffs and the attempts to realign the river to a high-water geometry. The current alignment fits a geometry that is highly variable, and in some locations the alignment is good, in others it is bad.

Many revetments were placed because of a need to "fight fires." Where a levee was endangered and the funds were short, a location for revetment construction was often chosen by necessity rather than by design. Unfortunately, the river has an affinity for hard surfaces, tending to scour a deeper channel adjacent to these hard surfaces (revetments) and retain that deep section for long periods of time. This action further retarded the river's response. In many locations it may be impractical to alter the fixed shape of the river; however, there are still reaches where the movement of sediments and high flows can be aided by a revised look at the "Master Plan."

7.04 Dredging. In 1824, the 18th U. S. Congress appropriated the first funds for the U. S. Army Corps of Engineers to begin improvement of the nation's waterways. The funds were used for research into the best way to remove the shoals in the Ohio River below the falls at Louisville, Kentucky, as well as any snags or trees that threatened waterborne traffic on the Ohio and Mississippi Rivers.

In the late 1800's, the railroads began to lure away potential river traffic because of the lack of a dependable year-round channel.

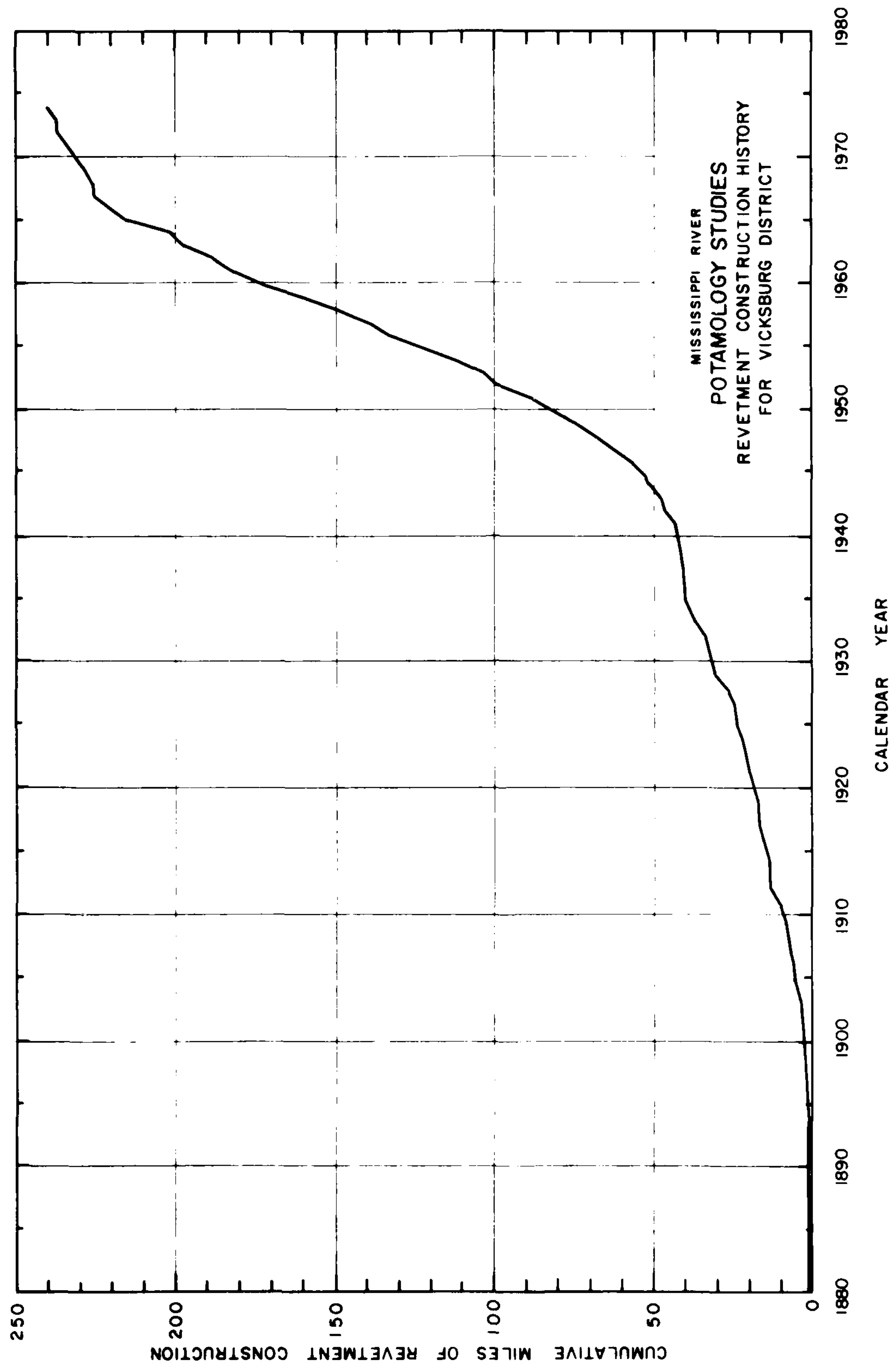

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
REVETMENT CONSTRUCTION HISTORY
FOR VICKSBURG DISTRICT
CUMULATIVE MILES OF REVETMENT CONSTRUCTION
CALENDAR YEAR
0
50
100
150
200
250
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980

Figure 51

To help solve the problem, the Corps began experimenting to find effective ways of causing scouring on the river bottom. These early efforts included stirring up the bottom by harrowing and plowing, in the hope that the current would carry the sand off. Nothing really worked until hydraulic dredging began in 1895.

For many decades, it was believed that the only method of maintaining navigation on the nation's rivers and harbors was by dredging. It is now felt that a great deal of the past dredging was unnecessary, and present and future dredging could be minimized through proper alignment and geometric controls.

Colonel O. H. Ernst (President of MRC, 1903-06) stated in reference to the Mississippi River:[4]

> A dredged channel which does not maintain itself is a very precarious foundation for trade. There is probably no place in the world where a dredged channel will have a briefer existence than in the uncontrolled part of the Mississippi River below the Missouri....Dredging has what seems to me the fatal defect of being dependent upon never-ending effort. It is a temporary improvement adopted from compulsion and not from choice....

Dredged material is considered a potential pollutant and currently much time and effort are being spent studying how, when, and where to handle this dredged material. The amount of dredged material requiring disposal might be drastically reduced if a study were made to eliminate the need for some of the dredging.

Stewart[11] had several concluding remarks that are worthy of discussion. Many of his ideas are still considered by some to be important in river work. The comments following each quote are those of the author.

> In view of the undeniably favorable results which have been obtained over the 10-year period, it seems not unreasonable to suggest that serious thought should be given to the greater use of dredges as a flood control medium...for such a general program, and to maintain the present gains, more and bigger dredges are needed. Sufficient experience has been had to lead to the belief that dredges of much larger capacity would be practical.

The most important considerations in the use of dredges on the river are the location and alignment of the cut and the disposal area. More often than not, the dredge as it is used works against, not with, the river's natural tendencies.

> Plan the work in such a manner as to obtain the assistance of the river's natural action, if possible. It has been found that much of the desired results can be obtained without directing operations contrary to a desired action. It appears that the river can be gradually trained to a desired course much more easily than it can be pushed bodily.

This is one of the most significant statements in Mr. Stewart's entire report, though not always adhered to.

> The ultimate aim should be to confine the low- and high-water channels to the same alignment. The reason for this appears obvious because if such a condition could be attained all factors would be working in the same direction.

This sounds very good, but in practice it is impossible to do. A river establishes its size and regulates its alignment and geometry according to the magnitude of flow. It is simply a matter of small rivers having small channels and big rivers, big channels. Unfortunately, the high flows in the Lower Mississippi River are about ten times larger than the low flows.

> In selecting the alignment for a cutoff, be certain that the proper angle of entrance is provided.
>
> In planning the construction of a cutoff or other entirely new channel, there is no economy in first constructing a shallow pilot channel with the expectation of its further development by natural action. In practically every case where this was tried, it was necessary to widen and deepen the new channel with dredges. This being the case, the pilot channel might well have been dispensed with.
>
> When opening a channel through clay or other highly resistant material, do not count on assistance from the river. It has been noted repeatedly that clay formation successfully resists erosion, with the result that invariably it is necessary to open the channel through clay almost entirely by dredging. Not to realize this may result in seriously retarding development of the new channel while awaiting natural action.

> Don't depend on the river to open the lower end of a channel when the obstruction in the upper end has been removed.
>
> Don't dredge immediately below a projecting point. The area protected by the point almost invariably is affected by eddies and slack water.
>
> Don't remove projecting points unless provision is made to hold the alignment of the friable shore immediately above the point. Experience has revealed that in practically every case where a point was removed without protection immediately above it, the friable material continued to erode, with the result that in a relatively short time a point again existed.

These are all very good statements if you must make a cutoff on any river; however, no change in river alignment, length, or geometry should be attempted before a thorough study of the problem has been made. "In judging the accomplishments of dredges, do not place major emphasis on the yardage output. It is the worthwhile results toward the objective which really count." This is common sense in any construction project.

> All should be realistic enough to recognize the fact that the gains which have been made will not continue *unless the improved river is maintained.* The natural tendency of the Mississippi River is to meander and deteriorate. To retain the gains which have been won will require maintenance and such new work as is necessary to retain the decreased length and the increased carrying capacity of the channel.

Unfortunately, the "increased carrying capacity" was limited to very short reaches, and the reaction to slope changes both upstream and downstream resulted in wide channels with divided flows. Recently, as the river has responded to the cutoffs, the reach of the cutoffs (Hardin to Glasscock) is reacting in a manner similar to a single cutoff; e.g., the Vicksburg District (VXD) is the cutoff with degradation upstream in the Memphis District (MD) and aggradation downstream in the New Orleans District (NOD), and the problems are just beginning.

It would be interesting to document the relationship of maintenance dredging to the cutoffs, but so many things were done to the river that it is difficult, if not impossible, to analyze the response to any one

project. However, in order to document the navigation problems and to see what influence the cutoffs may have had, a review of Mississippi River Commission reports to the Chief of Engineers was made. It must be remembered that part of the increase in dredging could have been the increasing navigation demands as well as other unknown factors. Table 23 is a history of dredging on the Lower Mississippi River and is divided into the three Engineer Districts, MD, VXD, and NOD.

Maintenance dredging has increased dramatically over the past 80 years. There has been some decrease in dredging requirements in the MD and some increase in volumes and locations dredged in the VXD, through the cutoff reach. Dredging requirements in the NOD seem to be increasing. The downstream shift of the coarser bed material is becoming evident in the growth of bars and divided flow reaches farther downstream, plus the general decrease of depths below Natchez. This change has been occurring slowly over the past 100 years but has been particularly noticeable during the past 15 years.

Maintenance dredging began in 1895. Between 1895 and 1931, a total of 74,736,875 cu yd were dredged in the lower Mississippi River. This averages slightly over 2,000,000 cu yd per year, with a high of 11,656,333, or 16 percent of the total of 37 years of dredging, in 1931 and a low of 197,947 in 1905. The year 1931 was very dry following the 1927 to 1929 wet cycle (Figure 10).

Table 23

History of Maintenance Dredging on the Lower Mississippi River

Year	No. of Crossings Dredged/Year	No. of Crossings Where 9-ft Channel Not Maintained	Location of Dredging 1962 AHP* miles	Total Amount Dredged cu yd
1895	4		MD 890-750	934,174
1896	8		MD 883-751	846,155

(Continued)

* Above Head of Passes.

Table 23 (Continued)

Year	No. of Crossings Dredged/Year	No. of Crossings Where 9-ft Channel Not Maintained	Location of Dredging 1962 AHP miles	Total Amount Dredged cu yd
1896	1		VXD 357	?
1897	15		MD 928-712	668,221
1898	11		MD 928-712	558,200
1899	10		MD 879-595	1,410,223
	1		VXD 577	202,000
1900	12		MD 879-720	1,145,558
1901	18		MD 865-690	1,166,465
1902	11		MD 873-684	813,300
1903	15	1	MD 890-690	891,098
1904	17		MD 881-625	2,149,734
1905	4		MD 882-730	197,847
1906	5		MD 882-730	297,300
1907	7		MD 882-709	1,151,739
1908	16	6	MD 932-620	1,567,766
	4		VXD 590-465	600,000
1909	16	2	MD 923-658	1,260,171
1910	18	7	MD 923-620	2,020,040
	2		VXD 570-441	401,000
1911	18		MD 928-711	1,160,330
1912	15		MD 885-716	1,260,671
1913	13		MD 928-595	1,747,346
	1		VXD 493	240,000
1914	17		MD 929-595	1,940,000
	4		VXD 590-369	400,000
	1		NOD 311	160,000
1915	9		MD 883-716	399,654
1916	20	2	MD 890-707	1,590,378
1917	16	1	MD 890-628	1,000,116
	1		NOD 309	327,000
1918	12		MD 850-620	476,499
	2		VXD 595-354	175,000
1919	9		MD 890-753	833,926
1920	5	3	MD 877-252	906,711
	1		VXD 423	110,000
1921	9	3	MD 877-620	900,930
	1		VXD 425	25,000
1922	20	4	MD 890-620	2,223,810
	4	3	VXD 595-380	200,000

(Continued)

Table 23 (Continued)

Year	No. of Crossings Dredged/Year	No. of Crossings Where 9-ft Channel Not Maintained	Location of Dredging 1962 AHP miles	Total Amount Dredged cu yd
1923	10	2	MD 890-650	1,906,110
	2		VXD 570,422	350,000
1924	15	4	MD 890-590	2,467,223
	4	1	VXD 590-353	860,000
1925	15	14	MD 890-590	2,001,555
	6	2	VXD 570-347	977,000
1926	10		MD 890-620	1,170,000
	2		VXD 540-432	320,000
1927	14	4	MD 913-620	3,001,599
	2		VXD 590-435	323,000
1928	15		MD 905-701	2,720,325
1929	32	9	MD 915-639	5,044,504
1930	34	32	MD 885-596	7,499,962
1931	41	23	MD 933-622	11,320,333
	1		VXD 347	336,000
1932	36	No data	MD 940-620	12,117,826
	3	available	VXD 592,480,415	443,017
1933	66	between	MD 934-592	28,673,173
	3	1932 and	VXD 582,480,415	1,810,785
	1	1940	NOD 300	208,215
1934	43		MD 905-592	27,354,524
	4		VXD 597-415	435,310
	1		NOD 300	45,300
1935	38		MD 927-620	42,970,285
	2		VXD 597,532	606,403
1936	52		MD 930-620	30,769,025
	4		VXD 596,565, 528,510	744,595
1937	54		MD 949-620	25,868,704
	6		VXD 587-358	1,569,616
1938	25		MD 888-598	19,624,409
	4		VXD 545,527 578,440	1,448,320
1939	56		MD 954-598	31,168,235
	14		VXD 578-350	5,349,289
1940	57	8	MD 948-598	31,521,101
	12		VXD 578-450	6,201,049

(Continued)

Table 23 (Continued)

Year	No. of Crossings Dredged/Year	No. of Crossings Where 9-ft Channel Not Maintained	Location of Dredging 1962 AHP miles	Total Amount Dredged cu yd
1940	1		NOD 300	450,000
1941	31		MD 980-627	14,932,635
	11		VXD 572-347	12,213,262
1942	25		MD 882-588	15,466,380
	8		VXD 565-347	18,717,037
1943	43		MD 948-618	22,037,000
	31		VXD 561-353	34,730,000
1944	40		MD 948-618	9,145,000
	28		VXD 557-330	18,881,000
	2		NOD 320-298	3,050,000
1945	29	1	MD 947-653	20,278,277
	14		VXD 557,320	6,120,075
	1		NOD 250	224,800
1946	35		MD 947-653	17,143,515
	15		VXD 570-361	10,925,235
1947	49		MD 947-605	30,407,310
	15		VXD 556-361	12,094,376
1948	42	1	MD 922-609	27,901,570
	16	1	VXD 558-432	12,273,230
	1		NOD 298	362,142
1949	36		MD 922-609	29,242,773
	10		VXD 593-320	9,223,574
1950	33	1	MD 925-610	23,099,977
	13		VXD 557-380	6,222,493
1951	33	1	MD 925-610	23,099,977
	13		VXD 557-380	6,222,493
1952	19	1	MD ?	17,557,132
	7		VXD 593-320	2,605,455
	1		NOD 301	1,490,285
1953	60	4	MD 954-593	33,632,454
	14		VXD 583-320	4,325,575
	1		NOD 297	132,545
1954	54	1	MD 954-593	36,588,976
	21		VXD 583-320	5,566,588
	1		NOD 297	373,852
1955	43	1	MD	29,839,459
	12		VXD	7,288,930

(Continued)

Table 23 (Concluded)

Year	No. of Crossings Dredged/Year	No. of Crossings Where 9-ft Channel Not Maintained	Location of Dredging 1962 AHP miles	Total Amount Dredged cu yd
1956	50	7	MD	34,395,666
	17	2	VXD	8,940,370
1957	48	4	MD	28,583,915
	16	2	VXD	5,806,922
1958	48	3	MD	29,141,031
	10		VXD	6,777,131
1959	39	1	MD	22,928,000
	12		VXD	6,908,000
1960	42	6	MD	22,949,000
	10	2	VXD	3,591,000
1961	35	2	MD	22,219,000
	5	2	VXD	3,907,000
1962	32	1	MD	26,764,000
	12			6,780,000
1963	36	5	MD	24,607,000
	19	2	VXD	6,054,000
1964	42	7	MD	28,416,000
	19	4	VXD	8,227,000
1965	34	2	MD	23,449,000
	17	2	VXD	13,328,000
1966	37	1	MD	28,679,000
	15		VXD	9,130,000
1967	32	No data	MD	29,172,000
	12	available	VXD	10,842,000
1968	37	after 1966	MD	35,206,000
	13		VXD	10,131,000
1969	32		MD	24,269,000
	10		VXD	10,348,000
	2		NOD	493,000
1970	30		MD	22,574,000
	8		VXD	18,300,000
	1		NOD	613,000

Figures 52 and 53 are illustrations of the number of crossings dredged per year in the MD and VXD, respectively. The number of crossings dredged per year increased during the period of the cutoffs and only recently decreased. Dredging requirements are higher today than before

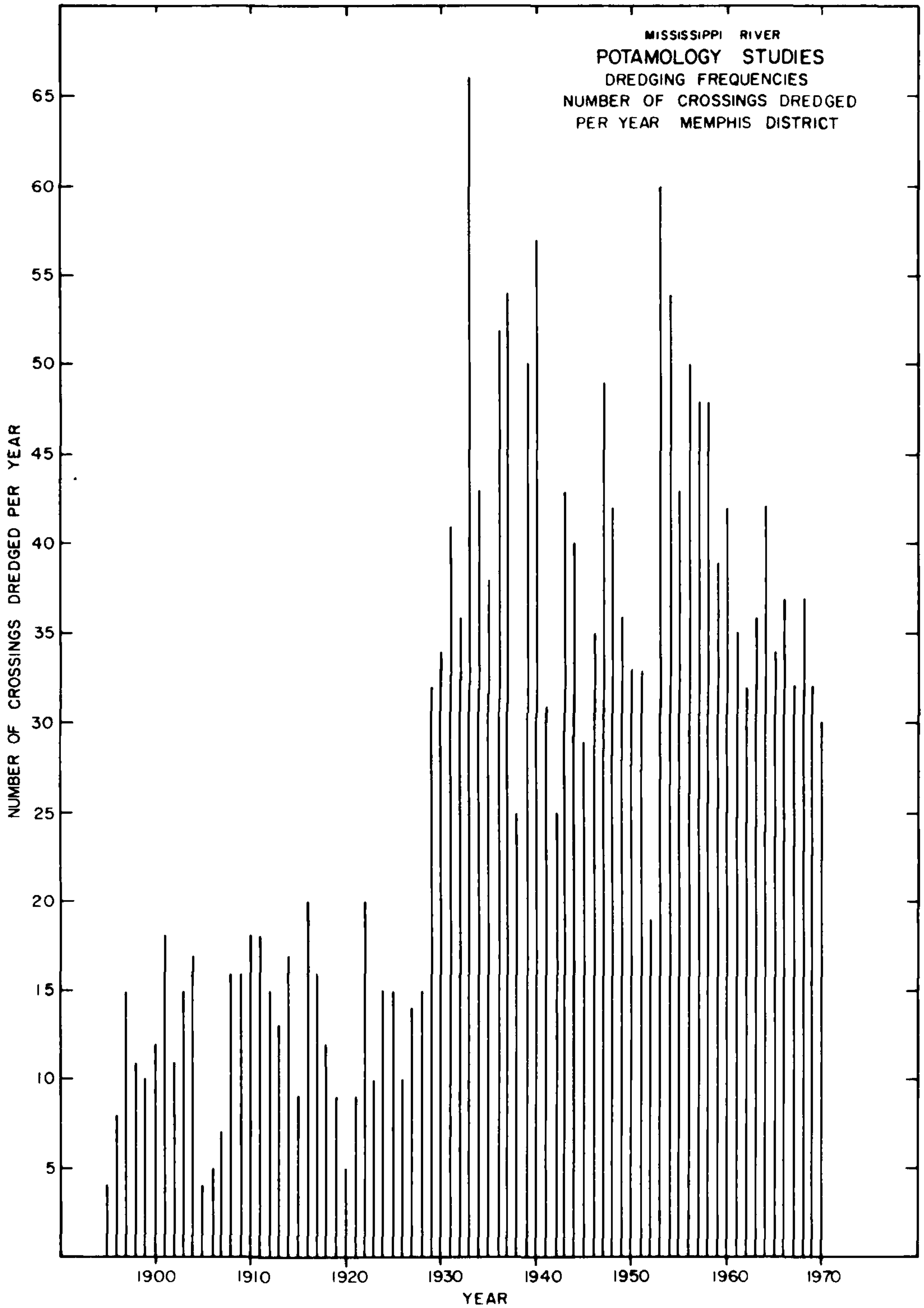

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
DREDGING FREQUENCIES
NUMBER OF CROSSINGS DREDGED
PER YEAR MEMPHIS DISTRICT
NUMBER OF CROSSINGS DREDGED PER YEAR
5
10
15
20
25
30
35
40
45
50
55
60
65
1900
1910
1920
1930
1940
1950
1960
1970
YEAR

Figure 52

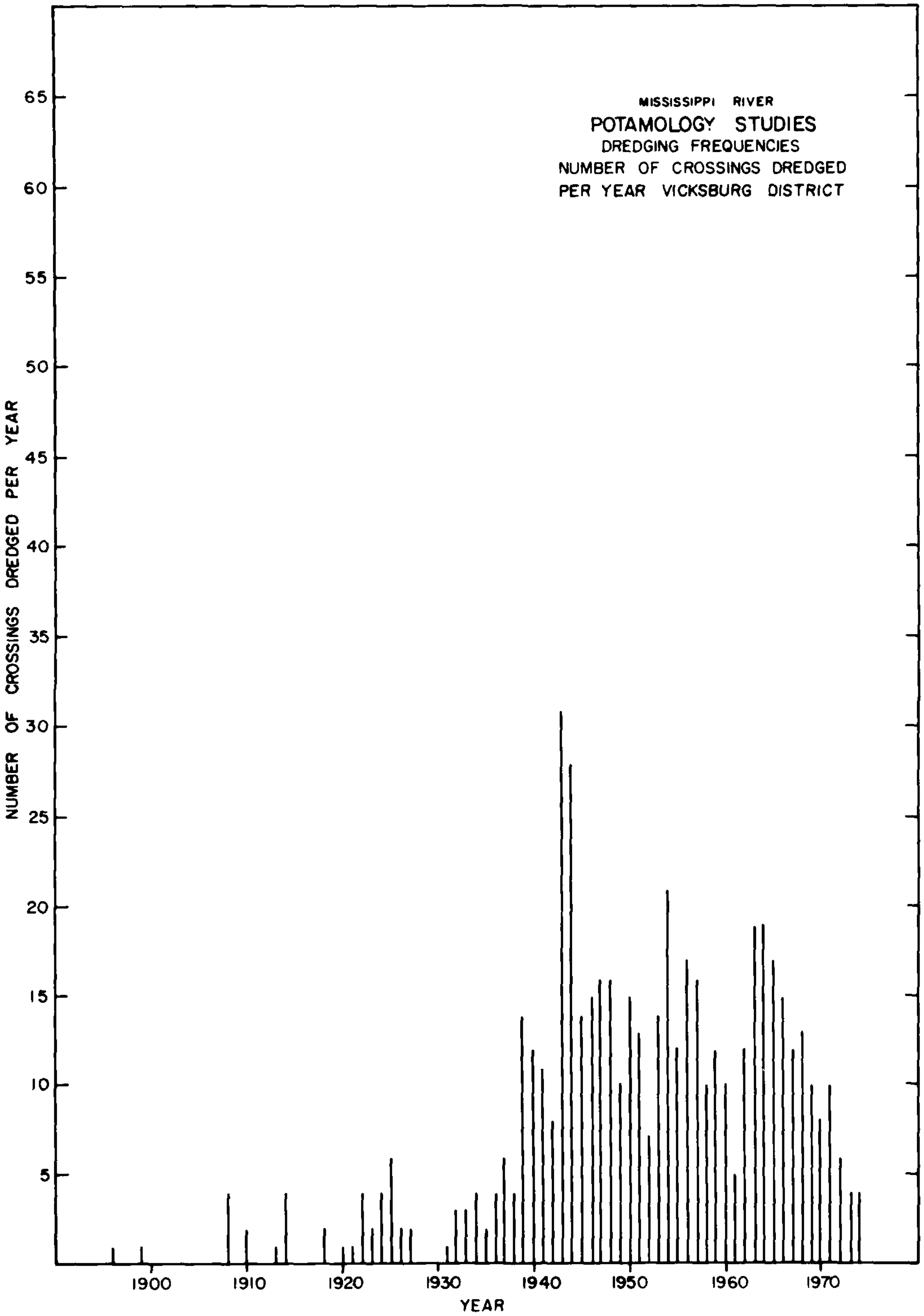

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
DREDGING FREQUENCIES
NUMBER OF CROSSINGS DREDGED
PER YEAR VICKSBURG DISTRICT
NUMBER OF CROSSINGS DREDGED PER YEAR
65
60
55
50
45
40
35
30
25
20
15
10
5
1900
1910
1920
1930
1940
1950
1960
1970
YEAR

Figure 53

the cutoffs. This could be either a result of the river response due to the cutoffs, recent navigation requirements, or possible other unknowns.

Dredging requirements vary with the hydrograph of flow. Crossing elevations increase with higher flows and decrease with lower flows, particularly in straight reaches. Figure 54 was made from Tables 4 and 4A of a 1932 report by B. Somerville.[16] This figure compares the average depth of all crossings between Hickman and Memphis and indicates a 3- to 5-ft decrease in the average crossing depth as stages increased from 2 to 12 ft.

The orderly movement of sediments over a wide range of flows requires a sinuous channel. Figure 55 compares depth below low water with sinuosity in four reaches of the Lower Mississippi from 1971 survey data. Crossing depths increase dramatically with sinuosity. Pool depth changes are not as pronounced, but all of the bendways in the reaches considered have revetment, making depths more uniform.

As stated in paragraph 5.02 of this report, a series of events, beginning with the 1811-1812 earthquakes, were causing the Lower Mississippi River to adjust its geometry. Navigation control had been gained prior to the cutoffs.

The following extract is from a 1933 Mississippi River Commission report:[4]

> As a result of dredging, there is now, with rare exceptions, a good navigable channel at all stages, with a depth of 9 ft for a distance of 842 miles below Cairo and a depth of not less than 35 ft for the remaining 240 miles to the Gulf of Mexico...Cairo to Memphis is maintained by dredging. Memphis to Vicksburg is maintained by limited dredging, and Vicksburg to Baton Rouge only needs dredging at rare intervals. The channel below Baton Rouge to the Head of Passes is deep enough and requires no dredging.

Dredging seems to have been the answer to maintaining the few crossings that were a result of poor alignment in a natural river. The cutoff program initiated excessive sediment movement. This, plus the resultant poor geometry, caused increased dredging needs. Revetment and dikes have forced a low-water channel but have not decreased total dredging requirements. If the river is to approach a self-maintained

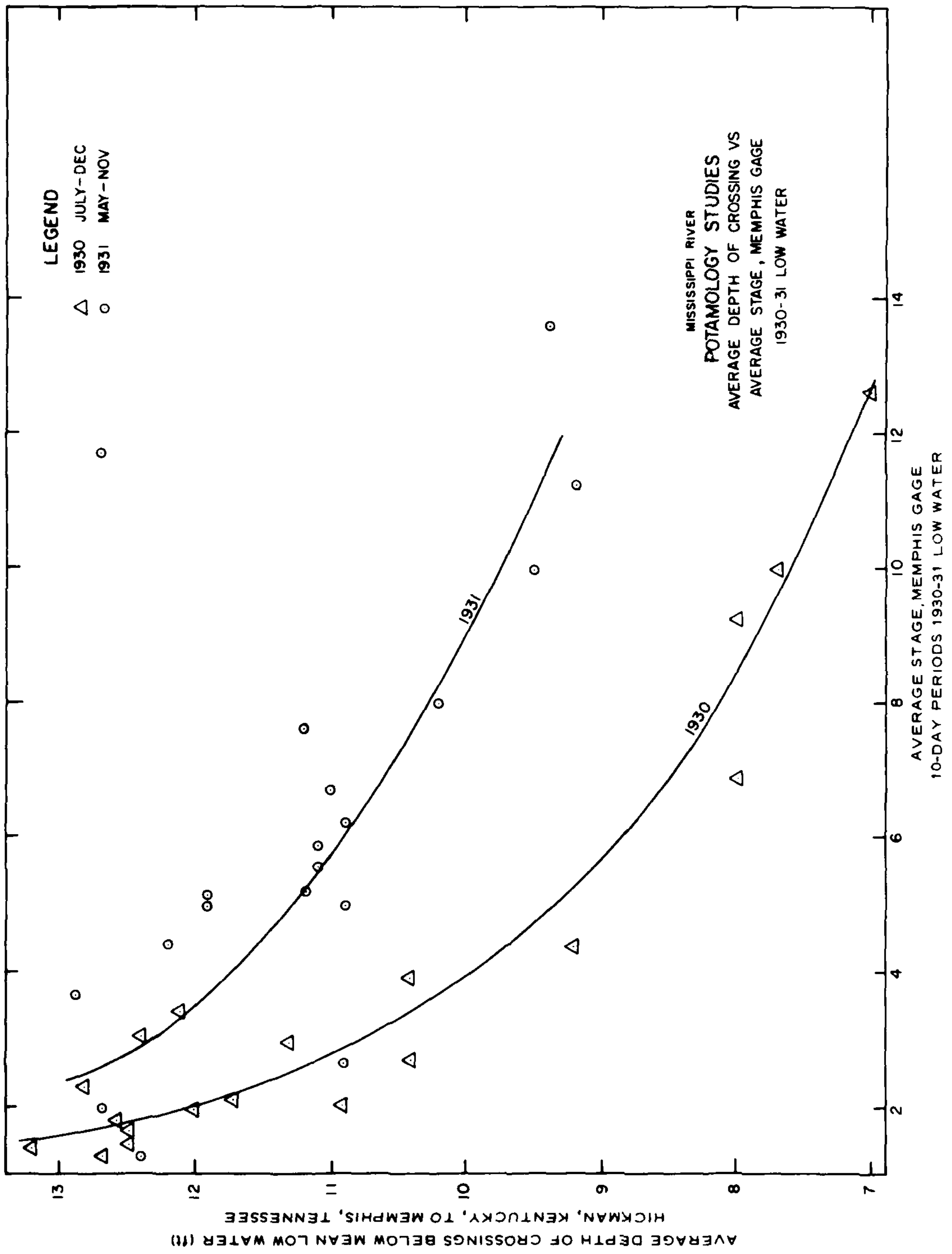

LEGEND
1930 JULY-DEC
1931 MAY-NOV
MISSISSIPPI RIVER
POTAMOLOGY STUDIES
AVERAGE DEPTH OF CROSSING VS
AVERAGE STAGE, MEMPHIS GAGE
1930-31 LOW WATER
1931
1930
AVERAGE STAGE, MEMPHIS GAGE
10-DAY PERIODS 1930-31 LOW WATER
AVERAGE DEPTH OF CROSSINGS BELOW MEAN LOW WATER (ft)
HICKMAN, KENTUCKY, TO MEMPHIS, TENNESSEE

Figure 54

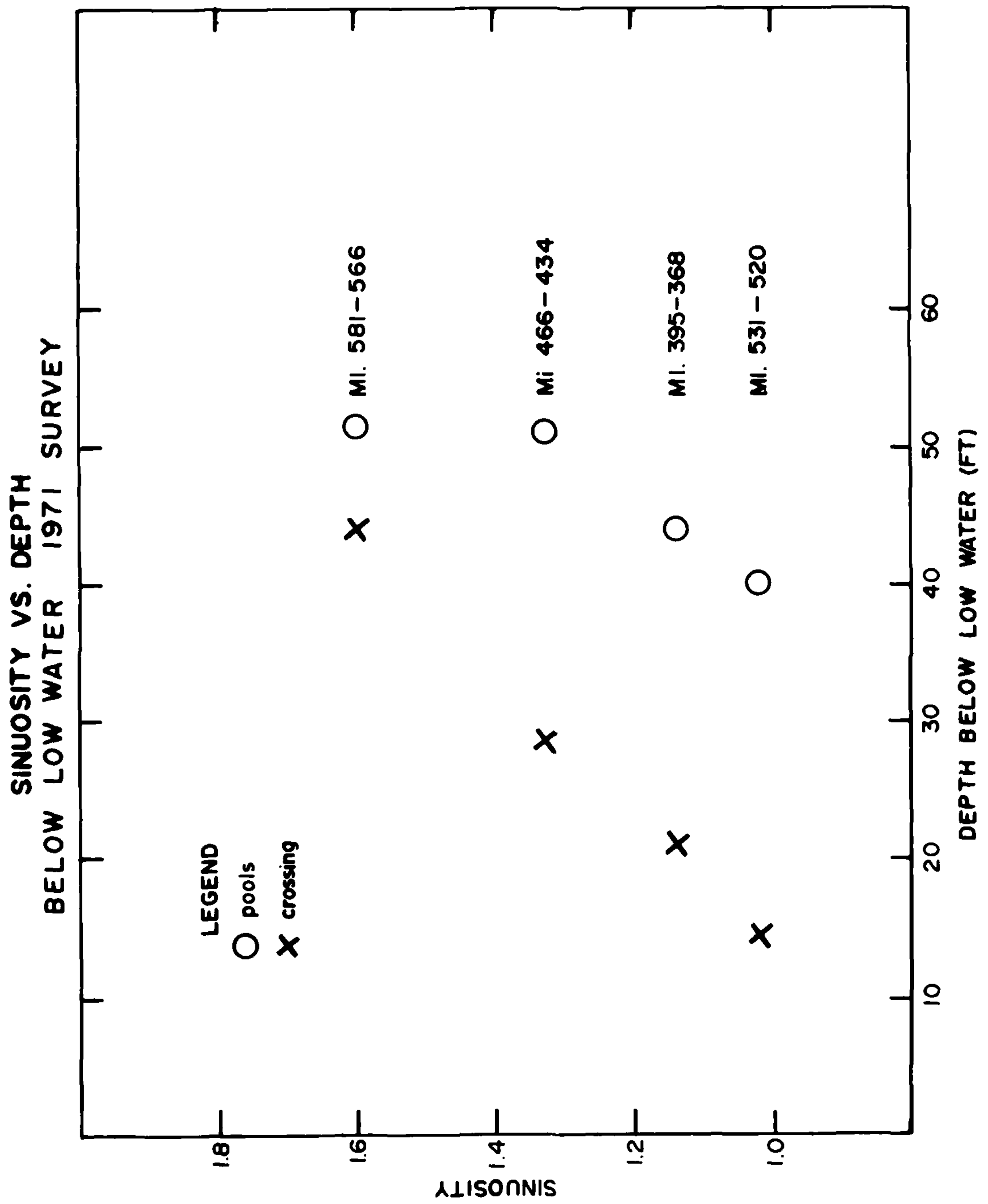

SINUOSITY VS. DEPTH
BELOW LOW WATER 1971 SURVEY
LEGEND
pools
crossing
MI. 581-566
Mi 466-434
MI. 395-368
MI. 531-520
SINUOSITY
1.8
1.6
1.4
1.2
1.0
DEPTH BELOW LOW WATER (FT)
10
20
30
40
50
60

Figure 55

condition, a proper sinuosity with better width control for all stages of flow is needed.

During the period 1930-1950, an attempt was made to dredge a channel that would be in alignment with the numerous cutoffs. Most of this "corrective dredging" was applied to development of secondary chutes and channels on the inside of point bars. Unfortunately the river could not maintain a high-water channel without an extreme expenditure of funds for dikes and revetment.

Table 24 lists the "corrective dredging" between Cairo, Illinois, and the White River and between the White and Red Rivers. This lists only the gross yardage per year. This "corrective dredging" is in addition to the "maintenance dredging" listed in Table 23.

Table 24

Corrective Dredging on the Lower Mississippi River, 1932-1955

Year	Above White River cu yd	Below White River cu yd
1932	12,142,986	10,422,696
1933	1,909,184	21,032,253
1934	15,083,369	24,811,765
1935	25,473,617	57,835,587
1936	0	18,056,649
1937	0	16,931,701
1938	9,484,282	40,176,264
1939	10,449,359	64,912,142
1940	17,231,374	56,445,380
1941	4,780,965	48,868,804
1942	0	12,601,422
1943	6,983,000	6,826,000
1944	16,012,000	6,084,000
1945	4,405,731	1,413,425
1946	0	0
1947	0	0
1948	0	1,320,719
1949	0	0
1950	4,650,076	0
1951	4,650,000	0
1952	0	0
1953	6,815,445	0
1954	3,241,186	0
1955	1,157,333	
Total	144,469,983	387,738,807

The volume in Table 24 does not include any normal required maintenance dredging at poor navigation crossings, only "corrective dredging."

Table 25 sums up the volume of dredging required to develop the cutoffs between 1932 and 1945 and the corrective dredging between 1932 and 1955. This table shows the extreme amount of maintenance dredging required during the period.

Table 25

Dredged Volumes on the Lower Mississippi River, 1932-1955

Type		Dredged Volume cu yd
Pilot channel in cutoffs		64,045,127
Additional dredging in cutoffs to develop		196,187,423
Cracraft and Opossum Chutes		33,087,284
Alignment and corrective dredging		532,208,790
Maintenance dredging		874,516,984
	Total	1,700,045,688

Much of the corrective dredging was only temporarily effective in accomplishing a better alignment for the river. As an example, the first field work was begun in December 1932 in an effort to develop the channel on the left bank between King's Point and Delta Point (1962 AHP mile 443 to 438). This reach had a bar in the center of the channel, poor navigation depths with poorly aligned crossings, and a sharp bend at Delta Point that presented difficulties for navigation and threatened the bridge approach at Vicksburg, Mississippi. After 10 years of corrective dredging (over 16,500,000 cu yd total) and construction of pile and sand dikes, the channel developed along the left bank. It has remained fairly trouble free except for a minor amount of maintenance dredging until recently. Some deterioration of the crossing at mile 439 is developing, and a series of training structures will be needed along the right bank to hold the pools and crossings in the abnormally long straight reach. The sharp bend at Delta Point has the same alignment as in 1932.

R. K. Stewart, in his 1945 unpublished report,[11] documents much of the work done in the VXD. Had the engineers of that time

realized that the river could not maintain any alignment that was not compatible with the movement of sediments and the variations of flows found in the Lower Mississippi River, they might have been more successful. Many of today's problems are a result of these "corrective" dredging activities.

Probably one of the worst techniques attempted on the river was the continued dredging of the chute (inside) channels on many of the bendways. In checking the records, it seems that the batting average was very high (about 0.750) in choosing the wrong channel. When it came to a decision of which channel to develop, the wrong one was chosen, thus continually upsetting the sequence of alternate bars that the river will attempt to maintain in spite of any activity by man.

From 1932 through June 1973, the VXD spent an average of $2,067,000 per mile on channel stabilization exclusive of dredging. This includes only the reach within the man-made cutoffs from Cessions to Glasscock.

It is concluded that much of the maintenance dredging, in the Mississippi River, plus other rivers (possibly), could be minimized through proper alignment so that bed sediments would move more uniformly.

SECTION 8. ALIGNMENT AND GEOMETRY

The advantages of the cutoffs were only temporary and the disadvantages may be felt for a long period of time. Very few of the cutoffs developed fast enough; most had to have several years of additional excavation before they passed both high and low flows. Much alignment and corrective dredging was necessary to hold the river in the new channels. Many bank stabilization and river training structures have been built, and many more will be needed before the river is controlled. As the river reacted to the cutoffs, it first entrenched itself and then developed a semibraided condition. Now it is attempting to reestablish meandering tendencies. Utilization of lands adjacent to present bank lines necessitates holding the river in its present alignment. This will require many expensive structures, as the river must be controlled from top bank to top bank, i.e., all stages of flow, in order to have good control of the sediments and discharges.

There are several factors that must be considered before making any analysis of geometric changes as a result of the cutoffs. During the period 1811-1812, the series of violent earthquakes in the vicinity of New Madrid, Missouri, surcharged the river with an excess of sediments and debris from the caving banks. These extra sediments had not worked their way through the system when man began tinkering with the river. The excess sediments tended to cause a wider and shallower river with more islands and bars.

During the next 100 years (until 1929), the numerous outlets into the St. Francis, Yazoo, Boeuf, Tensas, and Atchafalaya Basins were closed as the levee program was extended and levee heights were raised. As more and more water was confined to the main channel, all flows, particularly flood flows, were increased. This meant that all geometric parameters, such as slopes, widths, depths, meander wavelengths, meander wave widths, and radius of curvature, had to be altered in order to satisfy increased flows. Theoretically, these geometric changes should begin at the upper part of the river and work their way down through the system. In time, in order to accomplish this, every bendway

would be altered and moved. As the magnitude of flows increased, the distance between alternate bars and bendways had to increase from about 3.5 to 5 miles apart. This meant an extreme amount of bank caving. Thus, it is obvious that the river would need an enormous amount of time, much more than the 150 years since it all began.

Navigation and flood control needs dictated that dikes be constructed to shut off secondary channels and banks be revetted to protect levees, bridges, towns, etc. The river was never allowed an orderly adjustment of its geometry. General Ferguson's cutoffs actually aided this transition, and the extensive alignment dredging in the 1930's and 1940's further promoted the change to longer radius bends. This was part of the reason for the initial temporary benefits from the program.

Table 26 taken from W. H. Walters' report[17] shows the transition in progress from the earliest maps of 1765 to the 1930-1932 maps just prior to the cutoffs. All geometric parameters that could be measured show an increase in magnitude. Today's geometry has been further altered by the cutoffs and by the revetment and dike program of the past several decades.

Table 26

Summary of Lower Mississippi River Channel Geometry Data

Cairo, Illinois, to Red River Landing, Louisiana

Survey	Mean Radius of Curvature miles	Amplitude miles	Meander Wavelength miles	Sinuosity miles
1765	1.83 (62)*	3.98 (32)	7.48 (32)	1.76 (32)
1820-30	1.81 (67)	4.46 (34)	7.33 (34)	1.91 (34)
1877-83	1.91 (77)	4.12 (38)	7.74 (38)	1.73 (38)
1930-32	1.92 (65)	5.10 (33)	7.83 (33)	2.14 (33)

* Values in parentheses represent number of total measurements (after Walters[17]).

The extreme amount of dredging and construction has forced an alignment and geometry on the river that has a wide variation from reach to reach. The orderly movement of sediments is dependent on the geometry and alignment of the river; thus a variation in geometry and

alignment results in inconsistent flood and navigation control. Problems resulting from this will be felt for sometime.

8.01 Thalwegs. Man is not the only active agent in shaping the Mississippi River; nature has a very long and active history. There is a certain amount of consistency in 100 years of thalweg profiles in spite of all man has done to the river. The gravel in the alluvium, as well as the type and elevation of the Tertiary Formations, valley slopes, and evidence of faulting, seems to have a constant influence on the river's characteristics. Future work on the river must recognize these variations, and structures and alignment must be designed so as to work with the natural characteristics of the river.

8.02 Lengths. This extract from a 1962 Mississippi River Commission[4] report states:

> The cutoff program and the improvement of secondary or chute channels...resulted in a total initial shortening of 170 miles in the river between Memphis and Old River. The tendency of the river to meander and the curtailed bank stabilization program during World War II resulted in the river regaining part of its original length. However, the development of additional secondary channels and other improvement dredging has offset the increase to a major degree. This is borne out by the fact that the Red River Landing official mileage between Red River Landing and Cottonwood Point was 534.9 miles in 1942 and 538.3 miles in 1960, both distances being measured along the midmean low-water channels. Thus, the net gain in length has been 3.4 miles in the reach over which most of the channel improvement work was accomplished.

Figure 3 shows the length of the Lower Mississippi River over the past 2000 years. These data were taken from Fisk's report.[1] It indicates the consistency of total lengths under each meander belt variation and delta discharge location. Table 27 shows mileage variation between many points during historic times. The average length of the river from 1765 to 1924 was 1076.3 miles.

Figure 56 shows the length variation in the three engineering districts during the same period of time as Figure 3. The upper reaches between Cairo and Cessions show a length decrease as an adjustment to

Table 27

Comparison of Mileages Along Mississippi River

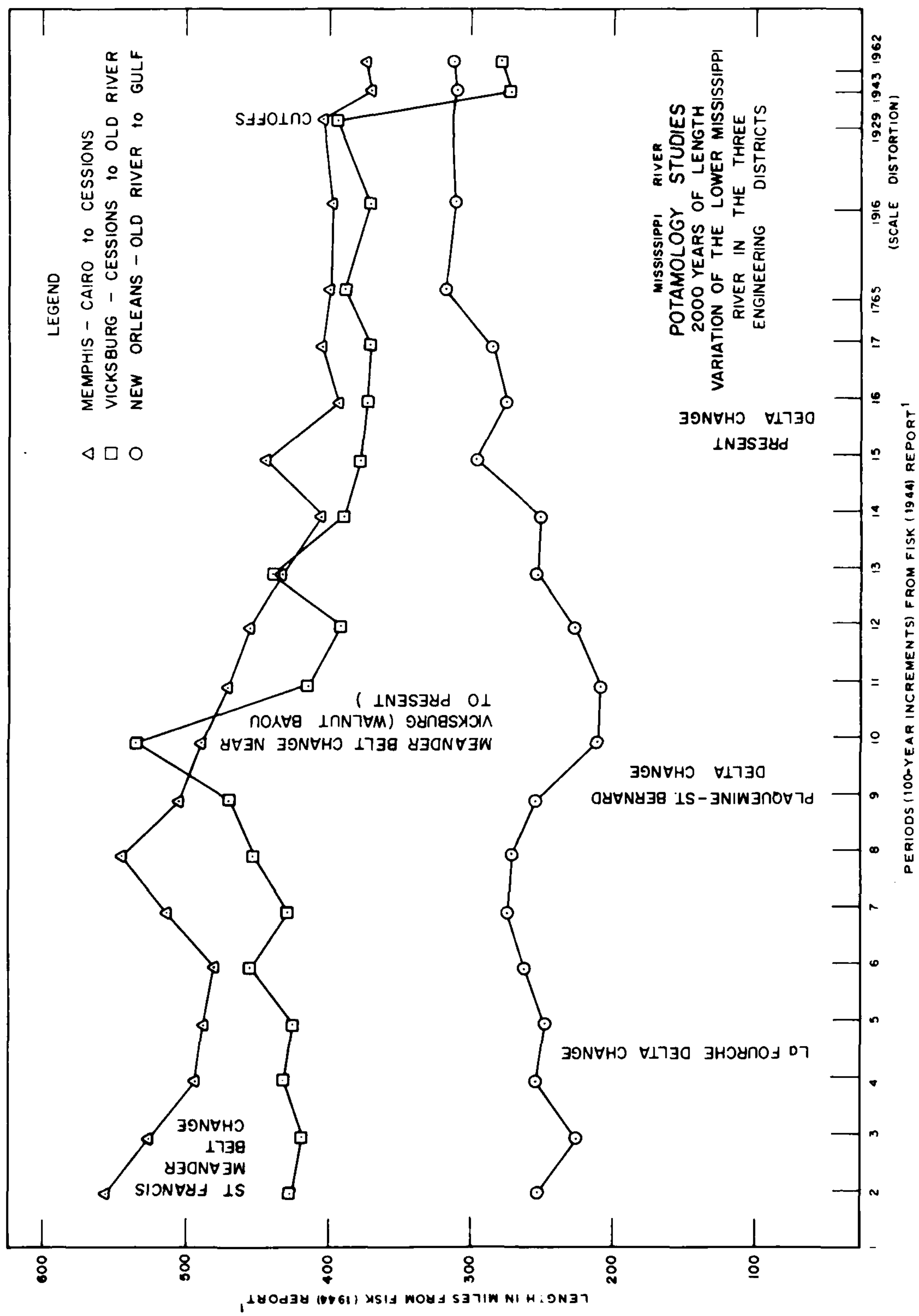
Below Cairo, Illinois

	River Mileage				
			Mississippi River Commission Map		
Gage	Ross Map 1765	1820 Period	1862	1916	1929
Cairo, Ill.	0.0	0.0	0.0	0.0	0.0
Columbus, Ky.	20.8	21.8	21.6	21.6	21.6
New Madrid, Mo.	63.3	66.0	70.3	71.0	71.2
Fulton, Tenn.	161.7	168.1	175.4	175.4	179.0
Memphis, Tenn.	224.6	227.6	230.0	227.0	225.5
Mhoon Landing, Miss.	271.3	275.0	276.3	273.2	271.1
Helena, Ark.	300.6	306.6	306.5	307.1	308.5
Mouth of White River, Ark.	386.0	386.0	393.2	391.7	396.4
Arkansas City, Ark.	428.5	435.0	438.3	436.7	443.5
Greenville, Miss.	455.7	467.0	478.3	480.2	487.5
Lake Providence, La.	532.0	545.0	542.3	543.0	551.6
Vicksburg, Miss.	603.0	613.0	599.3	601.8	609.7
St. Joseph, La.	657.5	676.0	648.3	662.4	662.7
Natchez, Miss.	696.5	722.0	700.3	705.7	708.2
Angola, La.	776.8	797.5	765.3*	771.4*	775.4*
Bayou Sara, La.	820.3	850.0	799.8	807.8	812.1
Baton Rouge, La.	849.0	884.0	833.3	842.4	846.4
Plaquemine, La.	866.0	902.7	854.1	862.8	866.8
Donaldsonville, La.	896.0	935.2	885.4	895.4	899.6
College Point, La.	913.8	953.2	904.5	913.1	917.2
Carrollton, La.	964.3	1005.0	957.0	966.7	970.8
Fort Jackson, La.	1047.0	1089.0	1039.0	1051.2	1055.2
Head of Passes	1067.0	1109.0	1059.0	1071.2	1075.2

* Red River Landing.

the reduced postglacial bed load and therefore a decrease in meander wave width. The reach from Cessions to the Red River had only a slight length decrease except for the meander belt change about 1000 years ago and the man-made cutoffs. From Red River to the Gulf there has been an increase in length due to delta extension. The middle reach, with a past history of constant lengths, is the reach where most of the cutoffs and chute developments were made.

Generalized flow characteristics are influenced over large reaches of river by major changes in valley slope, tributary input, and



LEGEND
MEMPHIS - CAIRO to CESSIONS
VICKSBURG - CESSIONS to OLD RIVER
NEW ORLEANS - OLD RIVER to GULF
MISSISSIPPI RIVER
POTAMOLOGY STUDIES
2000 YEARS OF LENGTH
VARIATION OF THE LOWER MISSISSIPPI
RIVER IN THE THREE
ENGINEERING DISTRICTS
CUTOFFS
PRESENT DELTA CHANGE
PLAQUEMINE-ST. BERNARD DELTA CHANGE
MEANDER BELT CHANGE NEAR VICKSBURG (WALNUT BAYOU TO PRESENT)
La FOURCHE DELTA CHANGE
ST FRANCIS MEANDER BELT CHANGE
PERIODS (100-YEAR INCREMENTS) FROM FISK (1944) REPORT
(SCALE DISTORTION)
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
1765
1916
1929
1943
1962
LENGTH IN MILES FROM FISK (1944) REPORT
600
500
400
300
200
100

Figure 56

alluvium. Localized variation in the above are, at times, more pronounced as a river adjusts to changes in any one or more parameters. The Greenville Bends (1962 mile 531 to 549) were developing during the same period that the Lakeport to Mayersville Reach was decreasing in length. One reach was balancing the slope adjustment of the other reach so that over fairly long distances sediment movement was balanced out. These two adjacent reaches have been two of the most troublesome in the past three decades because the slopes were greatly increased by the cutoffs. Revetments eliminated the possibility of the river making its own adjustment. Thirty years of fixing the river's position has now caused this adjustment to be felt farther and farther downstream. Figure 26 shows the length adjustments from mile 524 to 496 over an 800-year period and indicates the time of known cutoffs as well as the period of the development of the Greenville Bends.

8.03 Widths. The river continues to widen as part of its adjustment to changes in flow characteristics. Table 28 shows the width

Table 28

Average Top Bank Widths, Miles

Reach	Date of Survey					Increase from 1821-1975
	1821	1874	1911-15	1948-52	1973-75	%
Cairo to St. Francis R.	3800	5400	6400	6500	6340	67
St. Francis R. to Arkansas R.	3000	4900	5200	5000	7220	141
Arkansas R. to Vicksburg	2400	4700	5500	6000	6660	177
Vicksburg to Red R.	2300	4400	4500	4900	5810	152
Cairo to Red R.	3100	5000	5800	5900	6420	107

changes from 1821 to 1975 and indicates an increase in all reaches, primarily caused by the 1811-1812 earthquakes and the levee program. Concerning the width parameter, General Ferguson[5] states:

> Above the latitude of Baton Rouge, the river now has a varying width between levees which ranges from maximum of 15 miles to a minimum of 3/4 mile, and a varying width of channel section which, at bank-full stages, has a maximum of 7000 ft and a minimum of 2900 ft.

Today (1975) the minimum width is 2,500 ft, but the maximum is over 12,000 ft. Control structures, such as rock dikes, are the only currently known method of regulating the river's width. However, these need to be properly designed and placed in order to be more effective.

8.04 Depths. Table 29 gives the average depths at the deepest part of the pool and the shallowest part of the crossing for five surveys taken over 90 years. Even with the magnitude of the construction efforts, we do not have the crossing depths that were available 90 years ago. This is probably due more to the river adjusting to levees, to a poor alignment, and cutoffs than to training structures. This table

Table 29

Average Depths in the Pool and Crossing for Five Surveys

Reach	Average Depth Below MSL, ft Pool	Crossing
St. Francis R. to Arkansas R.		
Avg. 1879-84 and 1913-15	61	22
1948-49	60	21
1961-62	61	14
1970-71	65	15
1973 (Cessions to Arkansas R. only)	(82)	(21)
Arkansas R. to Yazoo R.		
Avg. 1879-84 and 1913-15	64	23
1948-49	58	20
1961-62	67	21
1970-71	66	26
1973	71	21
Yazoo R. to Old R.		
Avg. 1879-84 and 1913-15	81	29
1948-49	81	21
1961-62	81	22
1970-71	89	25
1973	84	22

also indicates the downstream shifting of the problems.

Williams and Graves, engineers from the Mississippi River Commission, stated in the discussion on Matthes' paper:[7]

> Effects on low water flow have been slight, but perhaps warrant consideration.... There has been no noticeable decrease in depths since the opening of the cutoffs.... Loss of valley storage tends to increase flows below the cutoffs....

The time response of a large, flat gradient river was too slow to be noticeable in 1947.

The maximum depth of pools shows the reaction to bank revetment; it does not indicate the average depth in the cross section. As bank caving was eliminated and the local source of sediment was minimized, the channel immediately adjacent to the revetment increased in depth, because the river's energy was no longer needed to continuously clear away the caving material and could deepen the channel as does a tight bend impinging on a nonerodible bank. The normal exchange of material from bank to bar was altered, and point bars could no longer increase in elevation until they were level with the flood plain, because each high water swept the sediment from the inner portion of the bar. This action caused the convex banks to recede eventually creating a wider section with a secondary chute channel. The average depth of the section was now shallower; during the high flows, the middle bar acted like a broad-crested weir and created a backwater effect that could extend many miles upstream. The result was <u>less</u> flow in the main channel, more navigation problems, and less channel conveyance during high water, with associated higher flood stages.

Concerning depths at permanant gaging stations, a Mississippi River Commission report to the Chief of Engineers[4] states:

> Points of fixed and invariable elevation have been established for reference at various locations on the lower river.... The following approximate elevations [Table 30] may, however, be listed as indicating the elevations of the bed of the Lower Mississippi at various points....

The elevations were noted to be the deepest part of the

Table 30

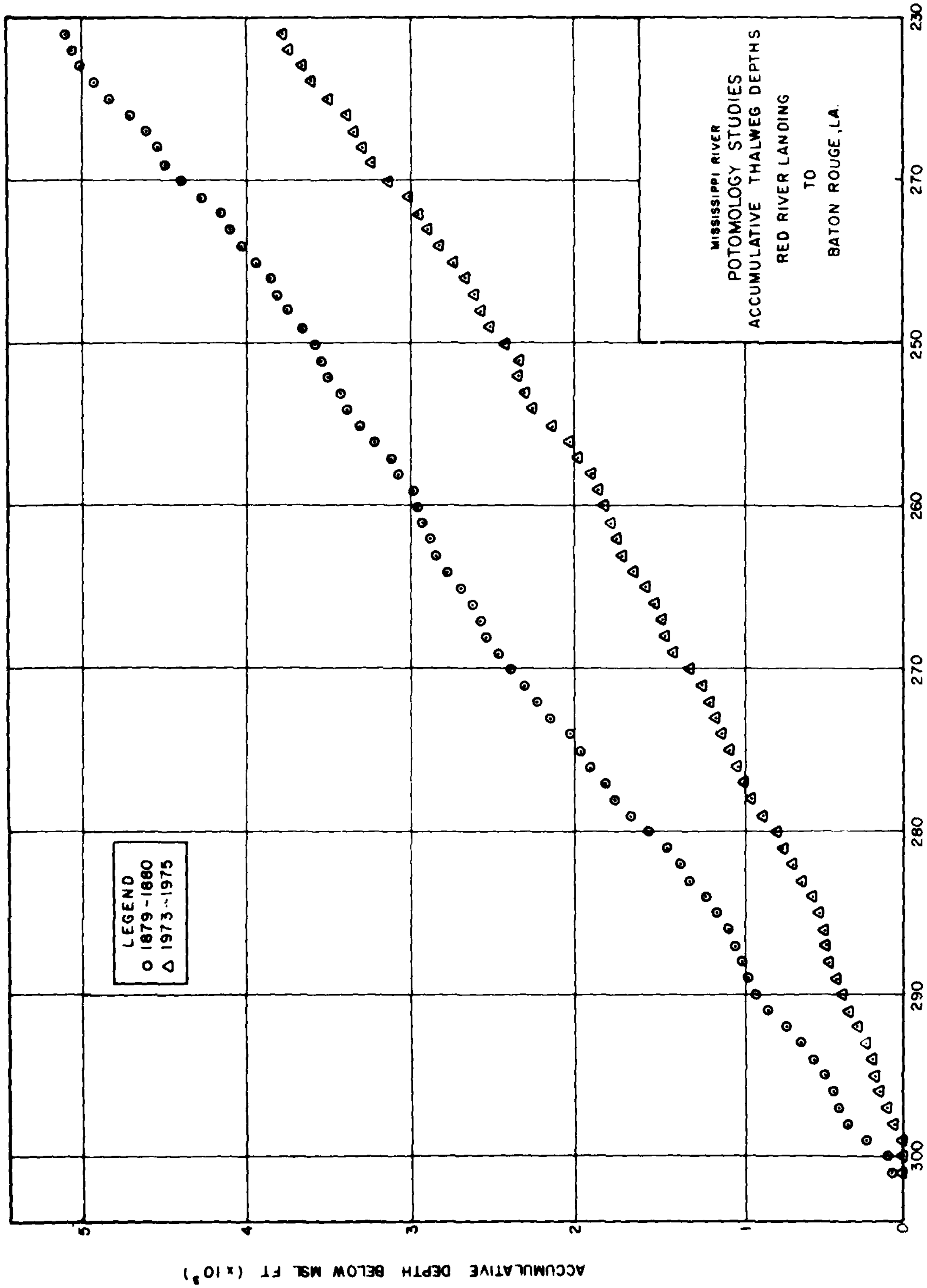
Depth of Riverbed at Main Gage Locations

Gage Location	Elevation, ft msl 1882	Hydrographic, 1943	Survey, 1968-75
Cairo	240	252	260
New Madrid	222	244	222
Memphis	121	112	132
Helena	135	108	120
Arkansas City	36	36	84
Lake Providence	38	38	38
Vicksburg	-16	-16	-48
Red River Ldg.	-62	-92	-34
Bayou Sara	-49	-18	-21
Baton Rouge	-72	-60	-59
New Orleans	-130	N.A.	-129 (1962)
Fort Jackson	-123	N.A.	-115 (1962)
Head of Passes	-54	N.A.	-43 (1962)

cross section at the named gages. Riverbeds shift, pools become crossings, etc., but these gage locations seem to have been fairly stable. The depths listed are only a measure of the deepest point at a particular time and do not account for possible local variation due to time, stage, etc.; however, they do show a general deepening upstream of Vicksburg and a general shallowing downstream.

Recent depth increases (Table 29) are probably the result of revetment and dikes, but these depths are "depths below low water," and so only indicate the navigation channel, not flood channel dimensions.

A measure of the thalweg depths of a river is only a two-dimensional look at the riverbed, but it does indicate problems are occurring. Figure 57 compares an 1880 thalweg depth with a recent survey and shows the accumulative loss of depths between Old River (Red River Landing) and Baton Rouge, Louisiana. Data points are at one-mile intervals. This loss of thalweg depth indicates the continued downstream shift of the coarse bed material. This movement is probably due to many causes, primarily, the decrease in meandering tendencies of the upstream river, the increase of flows within the main upstream channel from the levee construction, and the diversion of flow at Old River Control Structure. In a divided flow, neither channel, nor the combined efforts of both



MISSISSIPPI RIVER
POTOMOLOGY STUDIES
ACCUMULATIVE THALWEG DEPTHS
RED RIVER LANDING
TO
BATON ROUGE, LA.
LEGEND
○ 1879-1880
△ 1973-1975
RIVER MILES AHP
ACCUMULATIVE DEPTH BELOW MSL FT (x10³)

Figure 57

channels, can carry as high a sediment as a single channel.

8.05 Radius of Curvature. Current measurements of this variable are not meaningful because the river has assumed unnatural shapes in attempting to adjust to the revetted banks. The comparison in Table 26[17] shows the natural adjustment of radii due to levee influence and before today's anomalies of alignment were imposed on the river.

Figure 58 shows the variation between the curvature of bendways in 1932 and 1969. The 1932 river data are from a report to the Chief of Engineers[4] by C. W. Schweizer, Mississippi River Commission, prior to both the cutoffs and the extensive realignment and bank stabilization program. The 1969 data are from a Ph. D. thesis by Abdul Hannan[18] from data furnished by the Corps. The 1969 data do not include any measurements in 15 relatively straight reaches, which are a result of the channelization program.

There are more short (less than one mile) radius bends now, which create a navigation problem. If Hannan had measured the radii in the 15 relatively straight reaches, there would be more very long radii now than under natural conditions. Both the extra short and the extra long radii bends are a result of construction since the cutoffs. Separately, the short radius bends are usually the result of the river's reaction to building short, successive lengths of revetment; and the long radius bends, the result of cutoffs and chute development.

In 1932, 32 percent of the bends of the Mississippi River above the White River had some revetment; in 1969, only two bends had no revetment, and these were partially controlled by bluffs. In 1932, 50 percent of the bends between the White and Red Rivers had some revetments; in 1969, only five remained unrevetted, and one of these was controlled by bluffs. Between the Red River and Baton Rouge, there has been very little change in the river locations.

Figure 59 illustrates the cross section of five typical natural bendways. Most bendways in the Lower Mississippi River between the Ohio River and Old River Diversion have now developed a divided flow situation regardless of the radius of curvature. Bank revetment stopped migration, but the normal bar building continued. The result was a

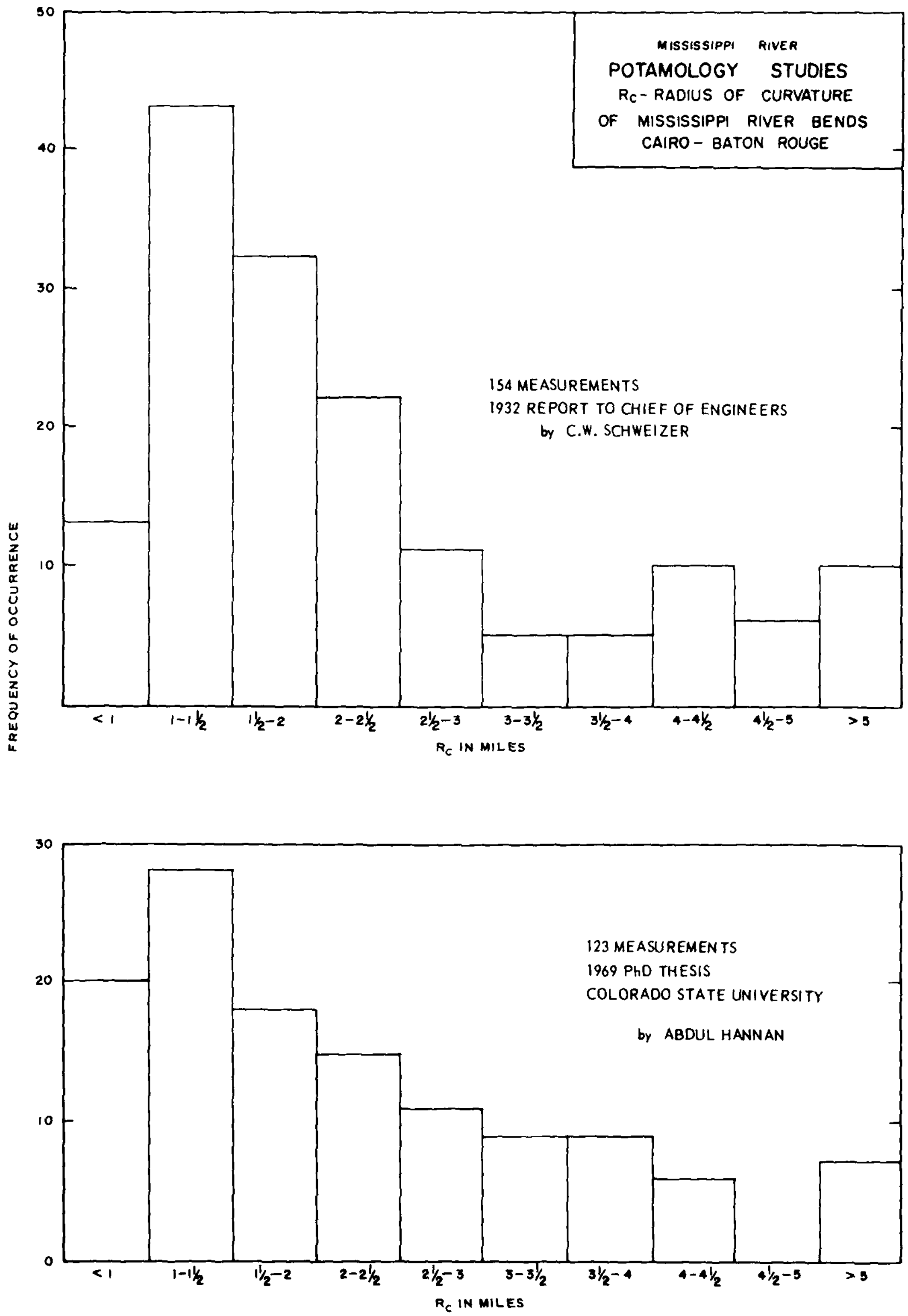

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
Rc - RADIUS OF CURVATURE
OF MISSISSIPPI RIVER BENDS
CAIRO - BATON ROUGE
154 MEASUREMENTS
1932 REPORT TO CHIEF OF ENGINEERS
by C.W. SCHWEIZER
FREQUENCY OF OCCURRENCE
50
40
30
20
10
< 1
1-1½
1½-2
2-2½
2½-3
3-3½
3½-4
4-4½
4½-5
> 5
Rc IN MILES
123 MEASUREMENTS
1969 PhD THESIS
COLORADO STATE UNIVERSITY
by ABDUL HANNAN
30
20
10
0
< 1
1-1½
1½-2
2-2½
2½-3
3-3½
3½-4
4-4½
4½-5
> 5
Rc IN MILES

Figure 58

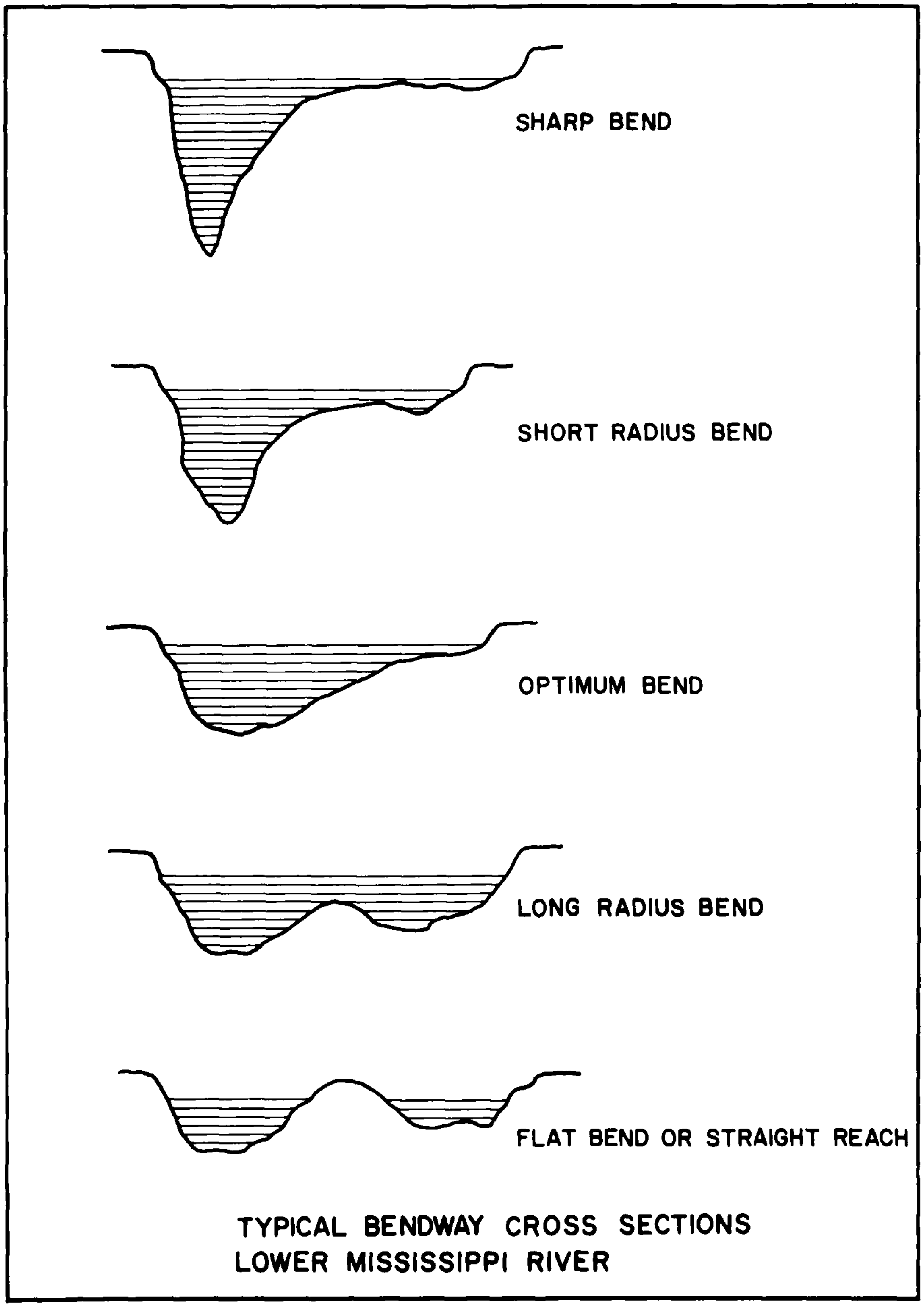

SHARP BEND
SHORT RADIUS BEND
OPTIMUM BEND
LONG RADIUS BEND
FLAT BEND OR STRAIGHT REACH
TYPICAL BENDWAY CROSS SECTIONS
LOWER MISSISSIPPI RIVER

Figure 59

narrower, deeper channel on the concave bank and a chute channel across the inside of the point bar. This chute was developed during high water, which not only scoured the channel bed on the inside of the bar but also caved the inside (convex) bank, producing a river with more width and a loss of channel efficiency from an increase in divided flows. Training dikes are the only currently known method available to help rebuild a more effective geometry and alignment.

8.06 Divided Flows and Bar Formations. A river builds alternate and point bars as a means of storing bed sediments between periods of high flows. Middle bars are usually a result of improper alignment and geometry and/or an excessive bed load. The latter may be due to hydraulic conditions or poor geometry tending to produce braided stream conditions. Cutoffs disrupt the sequence of alternating bars, increase slopes (thus increase bed sediment movement), and produce alignments that prevent the normal movement of the bed sediments in time and in magnitude.

Table 31 shows the dramatic increase in middle bars in recent years. This is part of the slow adjustment to cutoffs and steepening of slopes, with associated changes in sediment transport. The first reaction to the series of cutoffs was entrenchment followed by caving banks and widening of the river. The increase in bars is partly a result of the widening of top banks and the change in sediment transport capacities.

8.07 Number of Crossings. Any meandering alluvial river alternately builds bars and seems to space these bars at a repetitive down-valley distance. Between each bar is a "crossing," where the flow moves from the left bank to the right bank, and vice versa. The crossings are saddle-shaped, submerged continuations of the alternate and point bars and are a result of the varying sediment movement and direction of flow due to high and low stages. The "crossings" were so named by riverboat pilots, because they had to cross from one side of the river to the other in order to find water deep enough for navigation during low flows.

The Mississippi River Commission reports[4] on the river response to

Table 31

Divided Flow Analysis, Vicksburg District

Reach	Number of Divided Flows Per Reach in Each Survey				
	1879-84	1911-15	1948-52	1962-64	1973
Approximate length of river within study area	356	376	289	284	288
No. of divided flows	51	53	45	57	9
Helena to Cessions	7	5	5	6	12
Cessions to Arkansas R.	4	3	1	6	9
Arkansas R. to Greenville Bridge	10	12	7	12	17
Greenville Bridge to Lake Providence	7	10	10	10	12
Lake Providence to Vicksburg Bridge	10	10	8	6	13
Vicksburg Bridge to Natchez Bridge	6	5	6	7	19
Natchez Bridge to mile 320	4	4	4	3	8
Mile 320 to Baton Rouge	3	4	4	7	8

the cutoff state: "Navigation has been benefited not only by the mileage elimination by cutoffs and by chutes, but also through the elimination of about 30 crossovers in the channel that have been abandoned...." The river builds a consistent, repetitive geometry between major tributaries, so the number of crossings will always tend to remain constant. Figure 20 of the Greenville Reach in 1933 and 1975 indicates the same number of "crossings" even though the river length has been shortened 75 percent. Hydrographic surveys of the riverbed are only available for the past 100 years, and Table 32 lists the consistency of the number of crossings in various reaches of the river from these surveys. The recent increase in crossings is partly due to the increase in divided flows (bars).

A 1939 Mississippi River Commission report[4] on navigation changes

Table 32

Number of Crossings from Cairo to Red River

Date of Survey	Total	Cairo to Hardin	Hardin to Glasscock	Glasscock to Red River
1879-84	170	71	92	7
1911-15	178	76	95	7
1968-75	188	84	96	8

after cutoffs listed, for the years 1932 and 1939, the number and depth of crossings between Arkansas River and Red River. Table 33 summarizes the 1932, 1939, and 1975 data. The depth of crossings can vary depending on recent hydrographs and the stage of the river at the time of the

Table 33

Depth and Number of Crossings

Arkansas River to Red River

Date of Survey	No. of Crossings	Average Depth of Crossings, ft
1932	60	16.0
1939	46	11.5
1975	61	19.3

survey (Figure 54). However, the river has regained the same number of crossings and seems to have deeper crossings in this reach, probably a result of stabilization work.

8.08 Alignment and Sinuosity. The Task Committee on Preparation of Sedimentation Manual, Committee on Sedimentation of the Hydraulics Division of ASCE,[19] states:

> The straightening of a truly meandering channel over long reaches should never be attempted, even though the anticipated rewards in terms of increased capacity are tempting, unless one fully understands and is prepared to accept the consequences. There are many examples of the successful straightening of tortuous channels in erosion resistant materials, but there are also many examples where the straightening of meandering channels in erodible materials has resulted in severe headcutting in the channel

> and tributaries, excessive widening as the stream attempts to reassert its meanders, and the dumping of the eroded sediments upon downstream interests....

Various local agencies, as well as several Federal agencies, have been busy over the past 30-50 years straightening out the nation's rivers, streams, creeks, and drainage ditches.

The movement of sediments has not been understood and apparently never considered in detail. The size and the quantity of sediments are controlling factors in the final shape of any river channel (e.g., both plan and profile shape of the channel itself plus the meander belt). Lateral movement (width) of a meander is due to coarse bed sediments that the river deposits on alternating bars. A river with a large bed load will have caving banks and growing bars. A river with a small bed load is usually more stable. A river can have a very sinuous course because of some past sediment load that no longer exists. One of the simplest tests of whether a cutoff will be successful and will develop is: "How stable are the banks?" If there is active bar building and bank caving, then a cutoff will only aggravate an already unstable condition. In order to maintain a channel that will convey both sediment and water, a river with a high bed load, such as the Lower Mississippi River, must have a sinuous course. It is the only way that the river can balance the variation in sediment movement between high and low flows.

After making the cutoffs in the 1930's, an attempt was made to realign the river in long radius bends so that the high- and the low-water flows could be congruent. This increased the movement of sediments, and the period of bank stabilization that followed helped hold this increased slope situation on the river. The result was an accelerated downstream movement of sediment. For many years, the cutoff channels stored these excess sediments; however, during the past 10-20 years, the movement of these sediments was evidenced in additional bar building and an increase in the number of divided flows (Table 31).

Figure 55 compares sinuosity and depth for several "stabilized" reaches of the Mississippi River and indicates that depth increases with

sinuosity. Historically, the Plum Point Reach (1962 mile 803 to 783) and the Lake Providence Reach (1962 mile 495 to 482) have always presented navigation problems, and each has always had very low sinuosity. Since the 1929-1942 cutoffs, the reaches of the river with poor navigation records and high maintenance dredging have been the reaches that were straightened, such as the Greenville Reach and the Kentucky Bar-Mayersville Reach. Navigation control has been gained by forcing the river as in the Greenville Reach or by regaining sinuosity as in the Kentucky Bar-Mayersville Reach. However, it must be remembered that just any sinuosity will not do the job. Currently, the best sinuosity with the least maintenance seems to be about a 5-mile (measured along the thalweg) interval between alternate and/or point bars. The Cat Island-Commerce Bend Reach is an example of a reach with dikes and revetments forcing a sinuosity of about a 2.5-mile interval. During recent high water, this reach has experienced unusually high-dredging and maintenance problems.

SECTION 9. HYDRAULIC RESPONSE OF THE RIVER

An alluvial river adjusts to the conditions imposed on it. A series of natural and man-made events, starting in 1811, has kept the river in a constant state of transition, adjusting to a variety of conditions. The cutoff period initiated the most drastic response, but because the climate and discharge are so variable and sediment movement varies as a power function of the flow, the river can continue responding to imposed conditions for very long periods of time.

Samuel Shulits' remarks on ASCE Paper 2504[20] are as follows:

> The only records known to the writer of the long-range results of a rectification apply to the Rhine River from Basel, Switzerland, to Mannheim, Germany. The downstream portion of this extensive correction consisted of 18 cutoffs in the reach from Sandhofen to the Lauter River junction, executed between 1817 and 1842, reducing the thalweg from a length of 135 km (84 miles) to 85 km (53 miles), or 37 percent. Upstream to Basel, the rectification was accomplished by compelling the braided river to flow in a uniform bed. The entire correction caused a lowering of the bed in the period from 1820 to 1925, with the exception of a short stretch 20 km (12 miles) long. Of cogent significance is the conclusion of K. Wittman in 1927, after a study of more than 100 years of records, that the 250 miles of the Rhine River between Basel and Bingen, Germany, had still not been stabilized in 1925, even though some of the corrective works were then more than 60 years old.
>
> In January 1950, the writer (Shulits) inspected the Rhine River from Basel to Breisach, Germany, and learned that the degradation had not yet stopped.... Although 70 years passed before the degradation reached Breisach, a damaging degradation had been in progress since 1890. The Breisach low-water stage in 1947 was 2 m (6.6 ft) lower than in 1828....
>
> Any apparent stabilization after rectification must be regarded with a wary eye. At Mannheim on the Rhine River, degradation started in 1842 and continued to 1854, after which no change occurred till 1869. From 1869 to 1874, the bed dropped further and then remained unchanged to 1887, and since then there has been uninterrupted degradation. Between 1825 and 1925 the low-water stage sank a total of 1.5 m (4.9 ft). This can be

> attributed primarily to the cutoffs and the interplay of their individual cycles of degradation and aggradation. Thus, a steady-stage condition, even for 10 years, does not necessarily denote stabilization.

Degradation is not the only response of a river to cutoffs. Aggradation always occurs downstream, and bank widening is usually evident as a result of the instability actuated by cutoffs. Recently (1975), German river engineers were in the United States studying our rivers and methods of stabilization, because they are still having problems on the Rhine more than 150 years after beginning cutoff construction.

Commenting on river changes due to cutoffs, Lane[2] states:

> The changes which take place in erodible channels due to cutting off bends may be divided into two classes: (1) immediate changes, and (2) long-period changes. The first of these occurs immediately or within a short time after the cutoff is completed, and long-period changes are those which take place gradually over a period of considerable length, in some cases over a very long period of years....
>
> Assuming that the river (Lower Mississippi River) before the cutoffs was in substantial equilibrium, eventually some raising of the bed downstream will occur. So far as known, no rising has been observed, indicating that this effect, if it is occurring, is taking place so slowly that it may be many years before it becomes large enough to be significant.

On the Lower Mississippi River, it is difficult to measure the river response of each cutoff. If the reach in which the cutoffs were made is considered as a single cutoff, then can be seen degradation, channel straightening, and deeper flows upstream in the MD, and the downstream effects of aggradation, channel widening, and more bars in the lower VXD and NOD. Further simplified, there is degradation in the MD, braided stream effects in the VXD, and aggradation in the NOD.

On 10 January 1940, in the Annual Report to Chief of Engineers[4] on the over-all effects of the cutoffs G. H. Matthes stated: "...The forcast presented (in these tables) is reassuring in the sense that no drastic change appears contemplated." Mr. Matthes took too short a look (timewise).

9.01 <u>Hydraulic Variables</u>. The hydraulic variables are often the

only variables collected on a river. The hydraulic variables are the most dependent of all river parameters since they are constantly changing and adjusting to the magnitude of flow, to the changes in geometry, and to the varying sediment movement. Because the flow, sediment, and geometric conditions are never exactly repeated on a river, any hydraulic variable occurs only once at the point taken and at the time of acquisition. Many hydraulic variables cannot be directly measured; they can only be calculated from other data after making limiting assumptions. Therefore, without considering the geometry of the stream, the hydrologic trends, the movement of bed sediments, and the geology of the basin, the hydraulic variables can often be misinterpreted.

9.02 Regime Theory. T. Blench[21] explained this theory as follows:

> A regime channel is any natural or artificial channel that has a noncohesive bed material that moves at some stage of flow; the sides need not be so restricted.... The noun "regime" applied to a channel or channel reach is analogous to "climate" since it implies a behavior that is appreciated in terms of many fluctuating factors whose average values, over a sufficient period, are either steady or change relatively slowly.... The mind finds no difficulty in visualizing a climate or a regime as a relatively steady state of large erratic fluctuations.... Climate is defined as "the kind of weather over a period of years, based on conditions of heat and cold, moisture and dryness, clearness and cloudiness, wind and calm...". So "regime" may be defined as the "behaviour of a channel over a period, based on conditions of water and sediment discharge, breadth, depth, slope, meander form and progress, bar movement, etc...". Unconventionally, but descriptively, it could be called "the climate of a channel".... The term "in regime" used in the technical sense that the regime, over a period, does not change. Applied to a river there is an implication, as in saying that the climate does not change over a period, that the period must be several years to permit a proper judgment....
>
> There is no single sufficient test whether a channel is in regime. However, for rivers, the most powerful single necessary test is to plot curves of "specific gage" against time; if the curves neither rise nor fall consistently the channel is in regime in the vicinity of the gaging site for most practical purposes....

According to regime theory, the factors in a regime

are determined by dynamical laws; therefore, an in-regime system is one in dynamical equilibrium, and the equilibrium is normally stable; that is, it restores itself after a disturbance if the causes remain unaffected by the disturbances.... If the dynamical causes (e.g. discharge) of regime factors fluctuate about steady or secularly changing time-mean values (over a period) then the regime factors (e.g. breadth and meander length) must do likewise, and conversely. More generally, if any time-mean regime factor suffers a change, then the other time-mean regime factors in a physical law in which it appears must also suffer change....

River fluctuations in the range of self-adjustment may be enormous; so, although equilibrium values exist, there is no obvious way of determining them exactly. However, a variety of practical problems can be solved with useful accuracy by posing them suitable in terms of mean values of regime factors that are regarded as multiples - different for cases - of equilibrium values....

The idea of an equivalent uniform causative quantity, such as discharge or sediment charge, has come to be expressed popularly by the terms "dominant" or "formative." The terms appear to have been originated by C. C. Inglis[22]. He applied the term "dominant discharge" to the steady discharge that would produce the same meander length as a natural sequence of discharges; the steady discharge result was from models and the natural one from rivers of one rather general type; and comparison of the formulas for both permitted the relation of dominant discharge to the discharge statistic used for the rivers. It is to be noted that there is no obvious reason to expect an equivalent uniform discharge calculated from one phenomenon - for example, meander formation - to be exactly the same as from another, such as self adjustment of slope.

The term "regime" may be used instead of the preceding two, since regime factors are measured, ideally, by equivalent uniform values. In general literature, the terms may be attached loosely to arbitrary means, but with the implied hope that these means are fairly constant multiples of true equilibrium values....

The concept of equilibrium of graded streams was earlier defined by E. W. Lane,[23] who introduced the following relationship:

$$Q_s d \sim Q_w S$$

where

Q_s = bed material load

d = grain diameter (usually d_{50} size)

Q_w = water discharge

S = slope of stream

The relationship above indicates that if Q_w is a constant mean annual discharge and S is increased significantly as with cutoffs, there will be a corresponding increase in Q_s and possibly the mean d_{50} size. This expression merely indicates the direction of adjustment toward equilibrium by the stream when an imbalance is introduced.

The concept of the graded stream was introduced by J. H. Mackin[24] and is stated as follows:

> A graded stream is one in which, over a period of years, is delicately adjusted to provide, with available discharge and with prevailing channel characteristics, just the velocity required for the transportation of the load supplied from the drainage basin. The graded stream is a system in equilibrium; its diagnostic characteristic is that any change in any of the controlling factors will cause a displacement of the change.

It should be noted that slope is not the only factor that is automatically adjusted by the stream to accommodate external constraints affecting flow velocity. It is believed that changes in channel roughness should also be included with slope; however, Mackin makes no mention of it.

These considerations indicate that a stream in its natural condition is balanced about its controlling factors; if one or more of these are changed, then the entire system will attempt to adjust to the new condition. If allowed, in time, the river may return to its original condition, but if it is restrained (as by bank revetment), then the river may develop a new regime. This change can be very slow because so many factors (length, slope, width, depth, radius of curvature, distance between bars, or meander loops) must change, and each of these factors

produces an enormous amount of sediment in making an adjustment.

It is now apparent that the natural response (in time) to the cut-offs has eliminated most of the initial advantage gained. Because the river is no longer allowed to meander, adjustments must now occur within today's revetted banks. The only outlet for the excessive sediments is downstream movement to the Gulf. Unfortunately, the only energy source the river has is its slope, and as the slope flattens out, the energy to move these excessive sediments diminishes and aggradation occurs. Both the main stems of the Mississippi River and the Atchafalaya Basin are filling.

C. T. Yang[25] applied his concept of unit stream power in a paper describing river meanders. The basic laws needed to explain meandering channels should explain how changes in the factors, such as water discharge, sediment concentrations, channel geometry, channel slope, valley slope, and geological constraint, change the meandering channel characteristics. According to Yang, this law is the law of "least-time rate of energy expenditure" and can be expressed by the equation:

$$\frac{\Delta H}{\Delta t} = \frac{kY}{t} = \phi(Q\ ,\ S_v\ ,\ C_s\ ,\ G\ldots) = \text{a minimum} \tag{1}$$

where

$\frac{\Delta H}{\Delta t}$ = time rate of potential energy expenditure per unit mass of water in a stream reach

Δt = average time required for a unit mass of water to travel through the reach

k = factor for conversion between energy and fall

Y = fall of the reach

ϕ = function of external constraints applied to a stream

Q = water discharge of the stream

S_v = valley slope

C_s = sediment concentration

G = geological constraints which are dependent at least on the erodibility of soil, the grain roughness, and the stream valley width

Because a straight channel has a shorter length than a sinuous channel for a fixed fall, the value of $\Delta H/\Delta t$ for the straight channel is large; this applies to short as well as long straight reaches. The only possible stable unbraided channel pattern that can exist in nature is a smooth, sinuous meandering channel.

Equation 1 states that the value of ϕ (the independent variables) must be a minimum. Yang states that a channel will adjust its slope and geometry in an effort to minimize the $\Delta H/\Delta t$ value along its course of flow to approach a particular ϕ value imposed on the stream.

An increase in slope will increase $\Delta H/\Delta t$, which requires an increase of ϕ . This is contradictory to the law of least-time rate of energy expenditure. In order to satisfy this law, the stream has to decrease its slope by meandering until a new equilibrium condition is established. This seems contradictory, yet this is what nature does; and during the process of approaching equilibrium, nature overadjusts itself. Hence, a true equilibrium condition may never exist, but a dynamic equilibrium condition may be obtained.

When a cutoff is made, the increase in sediment concentration will first increase the upstream slopes and decrease the downstream slopes, then try to adjust its slope by meandering.

The $\Delta H/\Delta t$ value can also be minimized by increasing channel width, particularly where the channel is not allowed to decrease its slope after a cutoff. This is the type of reaction the Lower Mississippi River is experiencing.

Water discharge, Q , can be considered as an independent variable for a natural stream. In nature, a stream adjusts its slope and geometry to contain and to transport the water and sediment provided by the water shed. An increase in Q causes an increase in ϕ , which in turn causes the stream to adjust its slope and geometry so that $\Delta H/\Delta t$ will be a minimum according to its new value of ϕ . This higher Q will be associated with lower sinuosity and larger meander wavelength. This is what was happening to the river as a result of the levee program when the series of cutoffs were made.

Thus, both the discharge and slope have been increased, tending to

increase the ϕ value. In order to increase $\Delta H/\Delta t$ because of an increase in Q, the natural stream has to increase its slope, which in time causes a decrease in sinuosity. The levee program and the cutoff program then could have compensating effects, and the period of adjustment could be minimized. Thus, higher discharges should be associated with lower sinousity and larger meander wavelengths (as noted in Table 26). The questions to be answered are what is the final meander wavelength, how long will it take the river to adjust, can it adjust within the restricted revetted banks, and how should the downstream sediment movement be handled?

9.03 Slope. Normally cutoffs should be considered only when there are navigation problems such as too short a bend radius. Rivers with relatively flat slopes will adjust to cutoffs much easier than those with relatively steep slopes. On the Lower Mississippi River, the hydraulic variables seem to adjust to any high-water slope less than 0.5 ft/mile and, in time, to return the river to an equilibrium condition.

According to Ferguson,[3] "The river actually has shown itself sensitive to changes in gradient as slight as 0.01 ft/mile." Yet slope changes much more extreme than this were activated over hundreds of river miles by the cutoff program.

The speed and magnitude with which a river will adjust to any change is indirectly related to its slope. A flat gradient river such as the Lower Mississippi River takes an extremely long period to completely adjust to slope variations such as were imposed by the cutoff program.

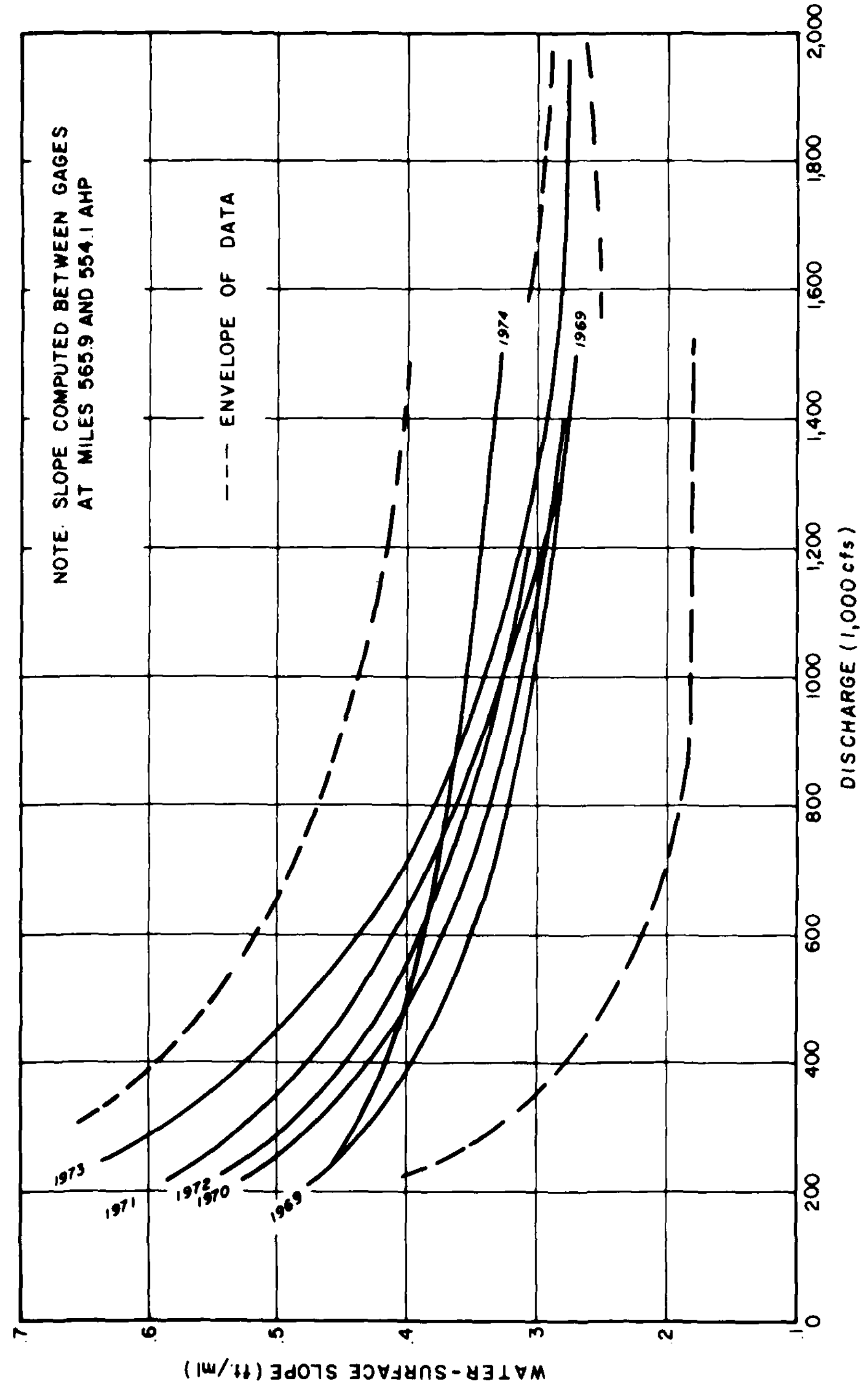
Table 34 shows the slope adjustments that the river has made at each cutoff. There is a wide variation in slope at any particular time, as well as a wide variation in the response of any one cutoff. This could be due to many things: (a) the local soil and geologic controls, (b) the valley slope, (c) the type of sediments in the bed, and (d) possibly the surges of bed material moving through a particular reach at the time of the survey. Figure 60[16] is a graph of six years of slope variation at a particular station. The Arkansas City Discharge

Table 34

Comparative Slopes Before and After Mississippi River Cutoffs

Name of Cutoff	Miles 1962 AHP*	Cutoff Net Shortening	Bank-full Slope Before Cutoff ft/mile	Slope Across Neck at High Water, ft/mile: Precutoff	1937	1945	1950	1961	1973	1975
Hardin	678.8-677.2	16.9		2.15		0.50	0.40			
Jackson	629.3-626.4	8.7		1.88		0.58	0.17			
Sunflower	626.4-624.2	10.4		1.45		0.51	1.50			
Caulk	576.5-574.5	15.2	0.17	1.45		0.58	0.95	0.55	0.45	0.65
Ashbrook	549.0-547.1	11.4	0.41	2.84	0.44	0.47	0.37	0.42	0.37	0.32
Tarpley	544.6-541.0	8.6	0.15	0.50	0.43	0.43	0.56	0.50	0.42	0.33
Leland	539.4-538.0	9.8	0.38	3.07	0.73	0.35	0.50	0.36	0.64	0.64
Worthington	516.0-512.2	4.3	0.46	0.97	0.71	0.70	0.39	0.34	0.32	0.55
Sarah	506.8-503.6	5.3	0.26	0.69	1.33	0.61	0.56	0.47	0.03	-0.09
Willow	464.0-460.5	7.7	0.32	0.85	0.41	0.36	0.37	0.54	0.46	0.26
Marshall	450.0-447.0	4.2	0.33	0.77	0.46	0.33	0.10	0.03	0.20	0.13
Diamond	426.0-423.5	12.0	0.15	0.85	0.10	0.19	0.16	0.36	0.08	0.00
Yucatan	408.6-406.0	9.6	0.30	1.45	0.47	0.57	0.35	0.31	0.27	0.35
Rodney	390.0-386.0	5.8	0.27	0.66	0.86	0.36	0.18	0.30	0.25	0.38
Giles	367.5-365.1	11.1	0.33	1.59	0.93	0.52	0.38	0.50	0.25	0.25
Glasscock	344.8-341.0	10.8	0.21	67	0.65	0.33	0.18	0.24	0.34	0.37

* Above Head of Passes.



MISSISSIPPI RIVER
POTAMOLOGY STUDIES
WATER-SURFACE SLOPE VS. DISCHARGE
ARKANSAS CITY DISCHARGE RANGE
MILE 565.9 AHP
WATER YEAR 1969 — 1974

Figure 60

Range has a stable cross section, but the downstream reach is very unstable, with middle bars and divided flows. These would influence the backwater curve of any river reach. Table 35 illustrates the slope in the reaches between cutoffs. Here, the slope variations are not as great and seem to be fairly constant over the past 40-50 years. Comparison of Tables 34 and 35 seems to indicate that the river has not completely adjusted to the cutoffs. A middle bar that has developed at the location of most of the cutoffs could be part of the cause of the wide slope variations, but it is also part of the river's continual adjustment to the cutoffs. This seems to indicate that there will still be several decades of adjustment before a stable condition is attained.

Figure 61 further exemplifies this transitional state. The two profiles are average slope lines of several floods prior to cutoffs and the floods of 1973 through 1975. This figure also indicates the recent degradation upstream and aggradation downstream in the 300 miles of river that contain all but 3 of the 16 cutoffs.

Figure 62 was taken from Fisk's map[1] and shows the slope-length variation over the past 2000 years. The data are divided into the three Engineer Districts. The MD, the upper third of the river, indicates an orderly adjustment toward steeper slopes as the heavy sediment loads of the glacial outwash were more uniformly distributed. The VXD shows an early reverse adjustment, probably due to glacial sediment loads, and then a progressively steady change until 1931, when the cutoffs caused a large slope adjustment. The NOD indicates a progressive flattening of the river as it built larger and larger deltas. Today's sediment movement is affected by these slope variations.

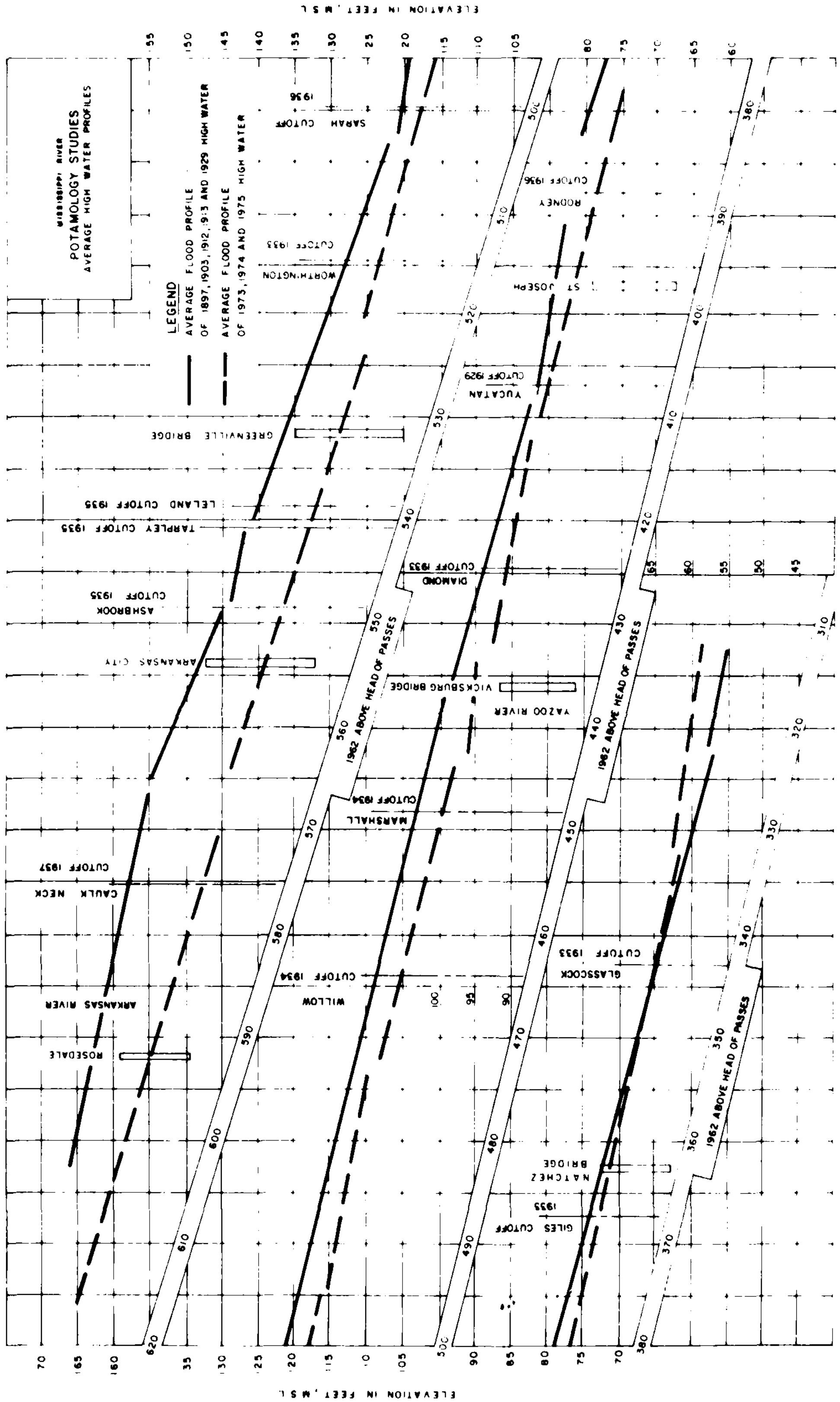
Usually only the river slope, under various flow conditions, is considered when studying river conditions. A complete analysis of river characteristics and response to work done on the river must also consider the valley slope and the thalweg slope, plus the slope of any geological formation that may influence depths of bed scour. In spite of all of man's activities, no apparent change has occurred in these controlling factors (the valley slope and geological influence on the thalweg slope), which seem to have more influence on the hydraulic characteristics

Table 35

Water-Surface Slopes on Mississippi River in Reaches Between Cutoffs from Downstream End of Opossum Chute to Upstream End of Glasscock Cutoff

Locality	Miles Below Cairo	Miles AHP*	Slope at High Water, ft/mile 1929	1937	1945	1950	1961	1973	1975
Foot Opossum Chute	530.9	503.6							
Head Willow Cutoff	564.0	464.0	0.35	0.35	0.34	0.32	0.38	0.37	0.39
Foot Willow Cutoff	577.7	460.5							
Head Marshall Cutoff	587.5	450.0	0.38	0.28	0.36	0.33	0.36	0.38	0.34
Foot Marshall Cutoff	593.2	447.0							
Head Diamond Cutoff	613.6	426.0	0.27	0.36	0.35	0.38	0.40	0.42	0.42
Foot Diamond Cutoff	626.0	423.5							
Head Yucatan Cutoff	640.0	408.6	0.21	0.27	0.27	0.32	0.38	0.32	0.36
Foot Yucatan Cutoff	648.0	406.0							
Head Rodney Cutoff	664.6	390.0	0.29	0.31	0.26	0.24	0.29	0.37	0.33
Foot Rodney Cutoff	675.0	386.0							
Head Giles Cutoff	686.0	367.5	0.24	0.28	0.28	0.30	0.32	0.34	0.28
Foot Giles Cutoff	703.8	365.1							
Head Glasscock Cutoff	722.8	344.8	0.24	0.31	0.22	0.25	0.30	0.29	0.26

* Above Head of Passes.



MISSISSIPPI RIVER
POTAMOLOGY STUDIES
AVERAGE HIGH WATER PROFILES
LEGEND
AVERAGE FLOOD PROFILE OF 1897, 1903, 1912, 1913 AND 1929 HIGH WATER
AVERAGE FLOOD PROFILE OF 1973, 1974 AND 1975 HIGH WATER
ELEVATION IN FEET, M.S.L.
1962 ABOVE HEAD OF PASSES
SARAH CUTOFF 1936
WORTHINGTON CUTOFF 1933
GREENVILLE BRIDGE
LELAND CUTOFF 1933
TARPLEY CUTOFF 1935
ASHBROOK CUTOFF 1935
ARKANSAS CITY
CAULK NECK CUTOFF 1937
ARKANSAS RIVER
ROSEDALE
RODNEY CUTOFF 1936
ST JOSEPH
YUCATAN CUTOFF 1929
DIAMOND CUTOFF 1933
VICKSBURG BRIDGE
YAZOO RIVER
MARSHALL CUTOFF 1934
WILLOW CUTOFF 1934
GLASSCOCK CUTOFF 1933
NATCHEZ BRIDGE
GILES CUTOFF 1933

Figure 61

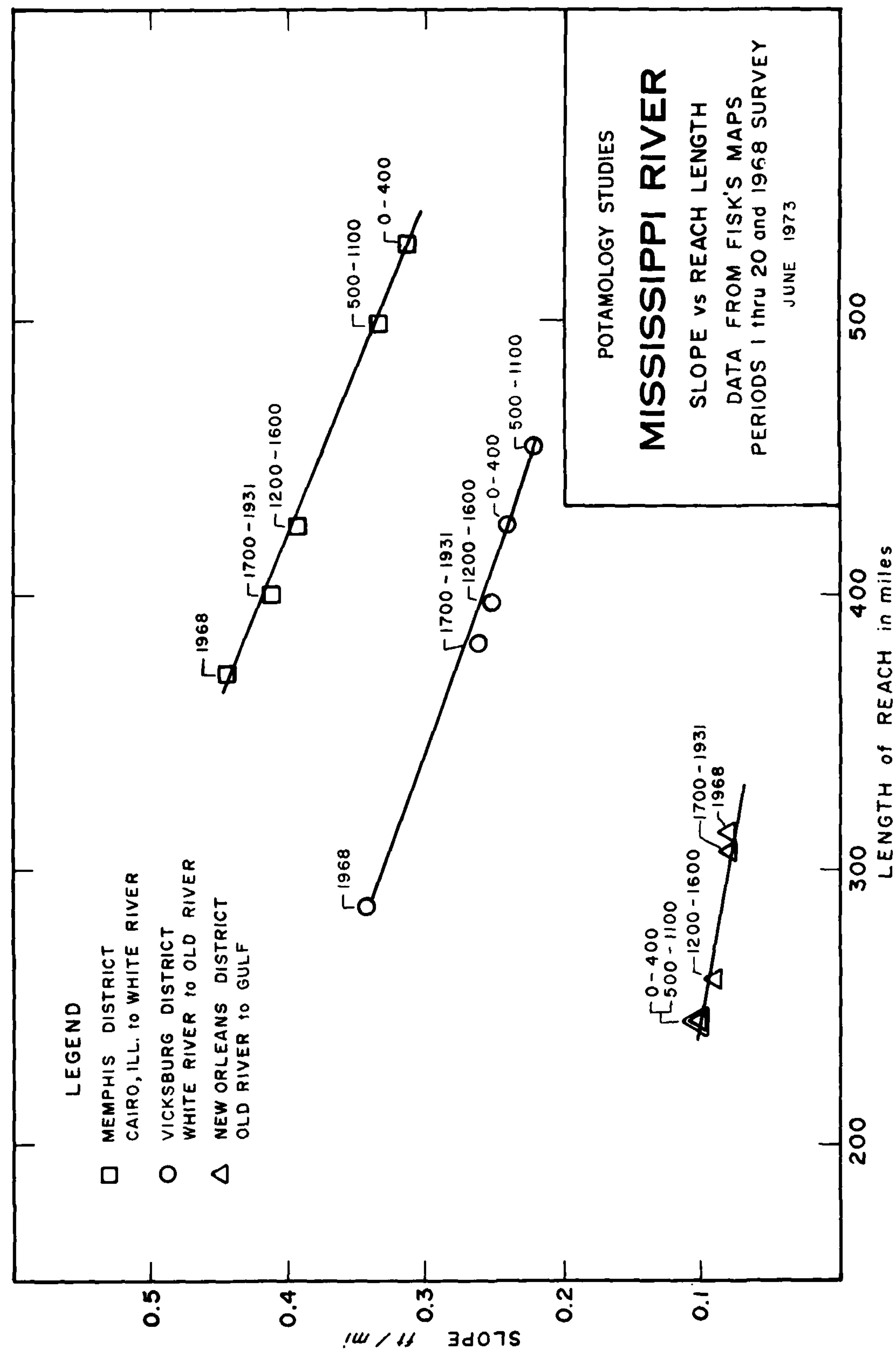

POTAMOLOGY STUDIES
MISSISSIPPI RIVER
SLOPE vs REACH LENGTH
DATA FROM FISK'S MAPS
PERIODS 1 thru 20 and 1968 SURVEY
JUNE 1973
LEGEND
MEMPHIS DISTRICT
CAIRO, ILL. to WHITE RIVER
VICKSBURG DISTRICT
WHITE RIVER to OLD RIVER
NEW ORLEANS DISTRICT
OLD RIVER to GULF
0-400
500-1100
1200-1600
1700-1931
1968
SLOPE ft / mi
0.1
0.2
0.3
0.4
0.5
LENGTH of REACH in miles
200
300
400
500

Figure 62

than local water slope variations caused by cutoffs. This is an area of river morphology that needs much more data acquisition and analysis.

9.04 <u>Velocities</u>. All alluvial rivers tend to have similar velocities related to particular flow events, i.e., low-water, midbank, and top bank flow, and floods of a particular frequency. Figure 63[26] includes data from rivers that are tributaries of the Mississippi-Missouri Rivers system. All rivers tend to hold velocities within a certain range. Bed forms and channel roughness are created that keep velocities within these limits; therefore, a permanent change in velocities indicates possible regime changes.

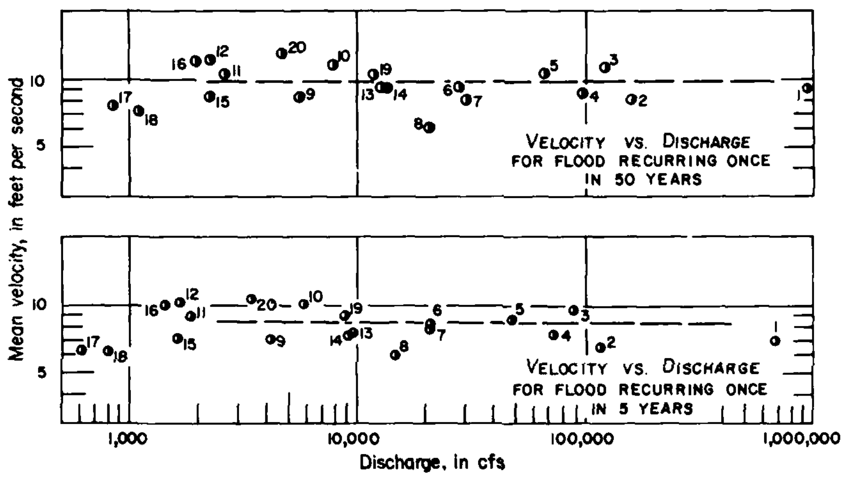


Figure 63. Velocity versus discharge for flood recurring once in 5 and once in 50 years (after Leopold, Wolman, and Miller[26])

Since slope was increased as a result of a decrease in length, through the cutoffs, a noticeable velocity increase would be expected. Figures 64 and 65 indicate that for a given discharge there was an increase in velocity following the cutoff program. As a general rule, velocity increases are not permanent as demonstrated by the average velocity changes at the Arkansas City Discharge Range (Figure 64). The 1967-1973 averages have decreased to near the levels of 1903-1931. The Vicksburg Discharge Range (Figure 65) shows an increase but no decrease, which could indicate a regime change. However, it should be pointed out

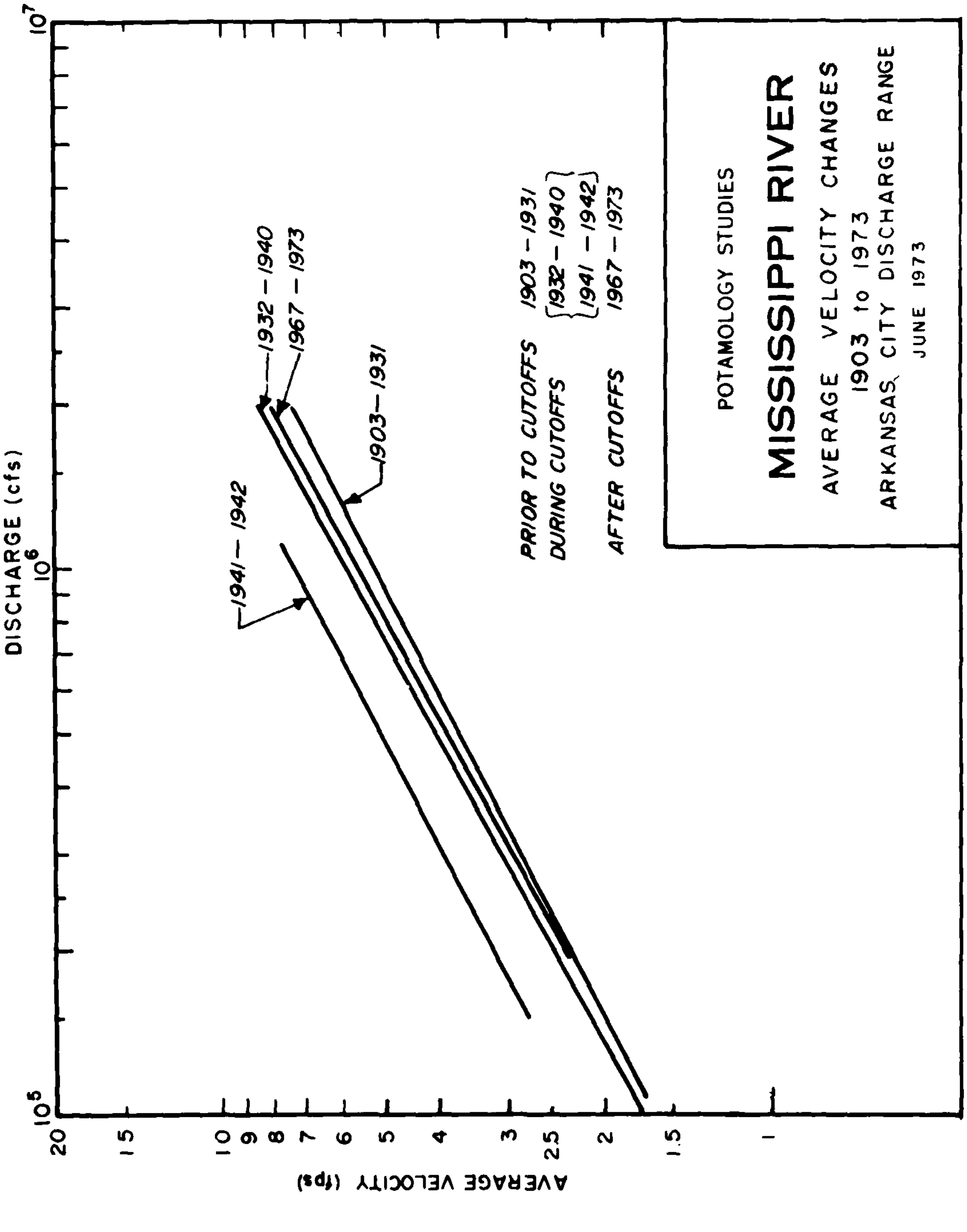

POTAMOLOGY STUDIES
MISSISSIPPI RIVER
AVERAGE VELOCITY CHANGES
1903 to 1973
ARKANSAS CITY DISCHARGE RANGE
JUNE 1973
PRIOR TO CUTOFFS 1903 - 1931
DURING CUTOFFS 1932 - 1940
1941 - 1942
AFTER CUTOFFS 1967 - 1973
1932 - 1940
1967 - 1973
1903 - 1931
1941 - 1942
DISCHARGE (cfs)
AVERAGE VELOCITY (fps)

Figure 64

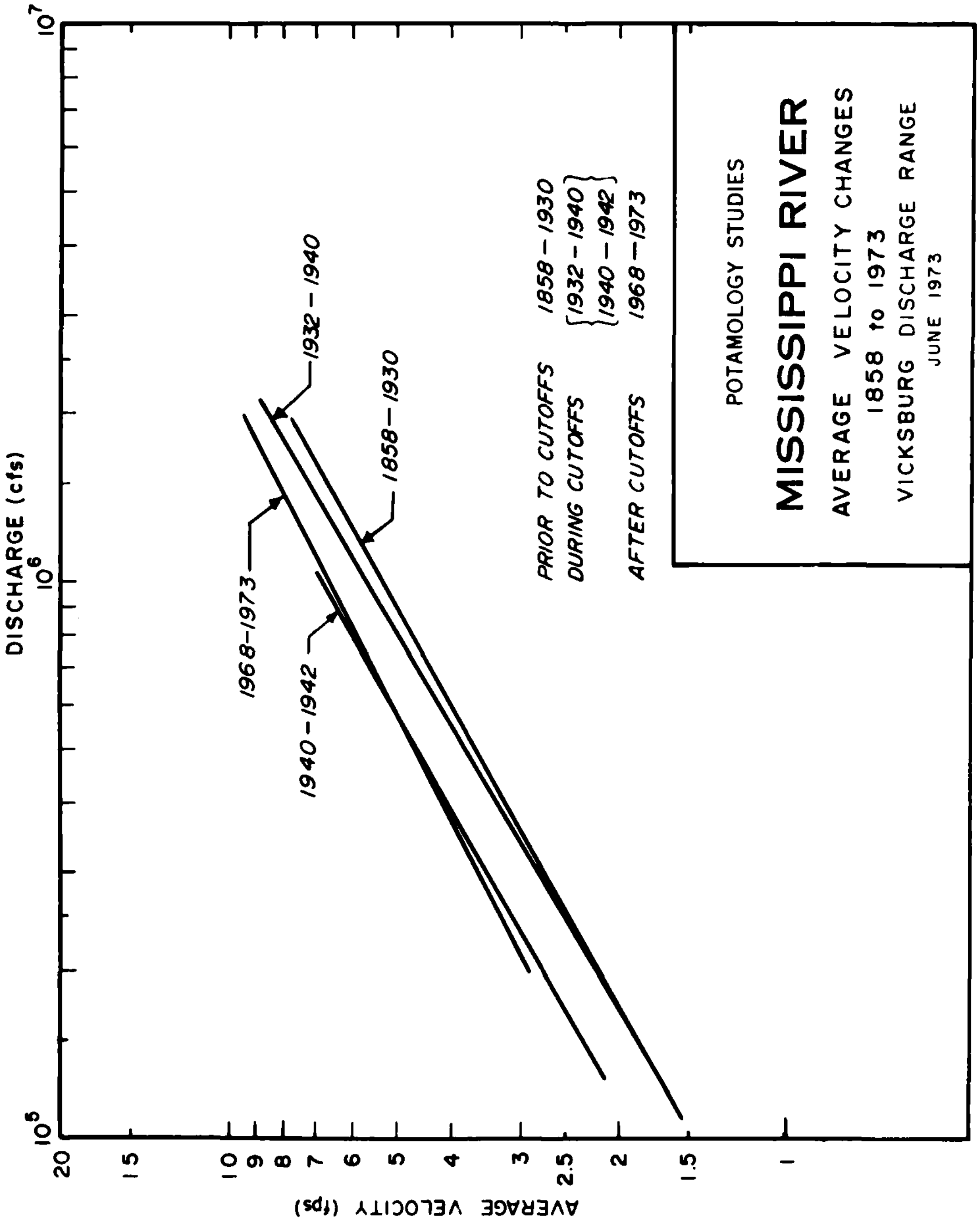

POTAMOLOGY STUDIES
MISSISSIPPI RIVER
AVERAGE VELOCITY CHANGES
1858 to 1973
VICKSBURG DISCHARGE RANGE
JUNE 1973
PRIOR TO CUTOFFS 1858 – 1930
DURING CUTOFFS 1932 – 1940
1940 – 1942
AFTER CUTOFFS 1968 – 1973
1932 – 1940
1858 – 1930
1968–1973
1940 – 1942
DISCHARGE (cfs)
AVERAGE VELOCITY (fps)

Figure 65

that the revetment program has attempted to hold the river in its post-cutoff alignment and also has decreased bank line roughness. This could also cause a change in velocity trends.

One of the main assets of the cutoff program was to be a decrease in time for a flood to pass through the valley. Between Arkansas City and Natchez the time of travel of the flood crests during the period 1915-1932 averaged 7.54 days and the period 1943-1975, 6.75 days. Using the 1932 distance between these points of 278 miles and the 1972 distance of 192 miles, the precutoff high water traveled 37 miles per day, and the postcutoff high water only 28 miles per day.

Flood waves are influenced by many things, so a simplified look, such as this, is not indicative of anything except that we have not changed velocities very much and probably have decreased, not increased, them as literature has indicated.

9.05 Discharge Prior to the 19th century, the river under natural conditions had an in-bank capacity of about 1,000,000 to 1,200,000 cfs, not much different from the present channel below New Orleans. Part of all flows and more of the higher flows were distributed through numerous outlets into the many subbasins. The main channel was rarely required to carry more than two thirds of today's in-bank capacity. During the 1800's, as numerous outlets were closed and the levees were extended, the channel was required to contain high discharges. Levees were breached with each major flood, but more of the low and intermediate flows were contained. The adjustment of the channel geometry was slow until the concentrated levee program after the Civil War.

In order to accommodate 50 percent more flow, every geometric variable had to adjust. This meant that every bendway and bar below and between points of geologic controls had to move. As a natural river, the meander wavelength of the Mississippi River was about 7.4 miles or 3.7 miles between alternating bars (Table 26) measured along the axis of the meander belt. Today, the river is not allowed to meander, so the meander belt is now confined between revetted banks. Even with this confinement, the bars are attempting to space themselves. Some alternate bars are developing on the concave side of bends, and point bars

have slid downstream into a straight reach between two bends. The present bar spacing seems to be about 5 miles or a 10-mile meander wavelength.

With these forced anomalies of alignment, the sediment transport has been altered, causing many changes from what might be termed a normal river. The final geometry will depend on many factors.

Natchez, Mississippi, is 365 miles from the Gulf of Mexico and at one time was downstream of many of the outlets. Figure 5 is the maximum yearly gage reading of record at Natchez for the past 175 years and shows the increase in bank-full stage as a result of closing outlets and improving levees.

As the channel was subjected to more and more discharge, it tried and is still attempting to reestablish a geometry that is compatible with the imposed flows. All of these changes cannot develop simultaneously throughout the entire lower river but must work their way in an upstream to downstream direction between fixed geologic control, provided sediment transport is not severely unbalanced. Table 36 lists changes in bank-full capacities at some of the major gaging stations.

Table 36

Variation in Bank-Full Capacities

Gage	Bank-full Stage ft	Year of Survey; Discharge, million cfs							
		1858	1882	1929	1937	1943	1950	1961	1973-75
Columbus	43	1.39	1.39		1.28	1.10	1.00	1.11	1.33
Memphis	34		1.27		1.00	1.10	1.25	1.14	1.31
Helena	41		1.42		0.90	1.00	1.21	1.14	1.24
Arkansas City	44		1.08	0.97	1.65	1.68			1.69
Vicksburg	43	1.08	1.16	1.04	1.30	1.45	1.70	1.41	1.29
Natchez	48		1.27		1.27	1.50	1.52	1.40	1.27
Red River	43		1.17	0.86	0.88	1.04	1.00	0.95	0.82

All gages were losing in-bank capacities prior to 1927 because of levee construction, outlet closing, and the channel's initial reaction to the increased discharges. After the cutoffs, the reactions are varied but generally indicate degradation upstream of Arkansas City and aggradation downstream.

A study of Table 37, which lists the 18 highest discharges of record at Vicksburg, indicates that recent floods seem to be of higher discharges. This could partly be due to levee confinment (no crevasses since 1927) and partly to changes in land use, thus more and faster run-off. Most reservoirs have been built during the past 40-50 years, which should tend to decrease flooding. Therefore, the higher discharges

Table 37

Highest Discharges of Record on the Mississippi River at Vicksburg, Mississippi, 1897-1975

Rank According to Flow	Year	Discharge cfs	Canal Gage* 0 = 46.25 ft msl	Rank According to Stage	Days Overbank
1	1927	2,278,000 est.	58.4	1	185
2	1937	2,060,000	55.5	2	43
3	1973	1,962,000	53.5	6	89
4	1945	1,922,000	49.8	15	47
5	1950	1,876,000	47.7	23	29
6	1975	1,832,000	49.9	14	32
7	1913	1,783,000	52.2	8	42
8	1912	1,780,000	51.7	11	72
9	1897	1,777,000	52.5	7	75
10	1922	1,752,000	54.9	4	70
11	1929	1,741,000	55.1	3	106
12	1916	1,735,000	53.9	5	90
13	1907	1,721,000	49.7	16	73
14	1943	1,671,000	45.8	28	9
15	1920	1,649,000**	50.9	12	78
16	1944	1,609,000	45.6	30	3
17	1903	1,606,000**	51.8	10	82
18	1961	1,578,000	47.3	24	12

* These are peak gage readings and are not necessarily coincident with the peak discharge.

** These discharges may have been exceeded during period of no record.

could be an indication of changes in the hydrologic cycle because over 40 percent of the United States drains down the Mississippi River. Another factor to be considered is the decrease of the natural reservoir of the floodplain.

A check of the histogram in Figure 10 of the mean daily flows indicates that of the nine years with the highest daily flows, eight have occurred since cutoffs began in 1929, with three occurring recently in 1973, 1974, and 1975. The wet years seem to be grouped in series of three each, so Table 38 was prepared to show the magnitude of each three-year cycle of high flows.

Table 38

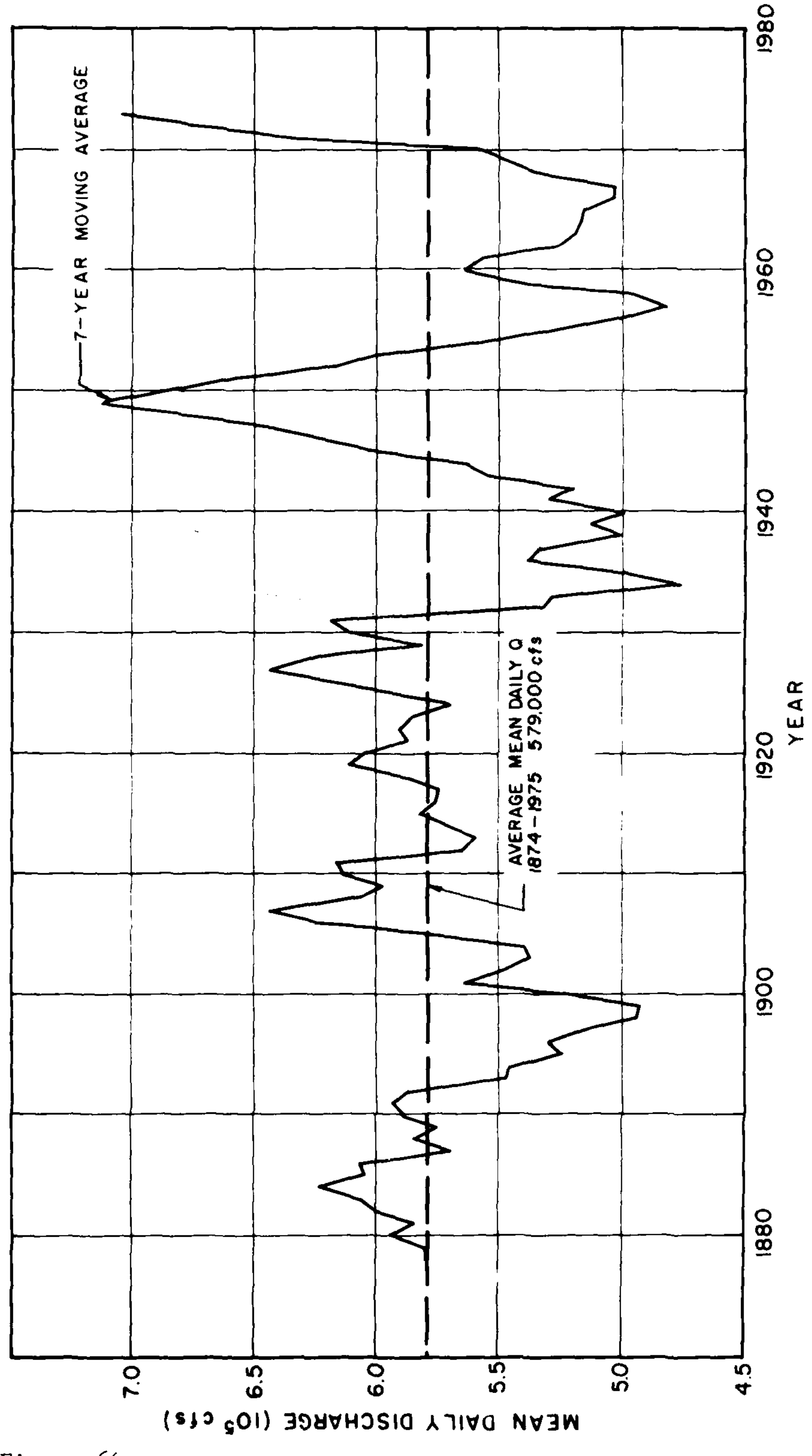
Highest Three-Year Periods of Discharge at Vicksburg, Mississippi

Years	Mean Daily Discharge at Vicksburg, cfs	Average Daily Discharge Year for the 3-Year Period cfs
1973	980,200	
1974	814,748	857,148
1975	776,000	
1927	905,000	
1928	708,000	796,667
1929	777,000	
1949	690,800	
1950	872,100	789,067
1951	804,300	
1907	740,000	
1908	717,000	700,667
1909	645,000	
1943	637,300	
1945	817,000	691,500
1946	620,200	
1890	766,000	
1891	596,000	688,333
1892	703,000	
1882	730,000	
1883	645,000	683,667
1884	676,000	

Counting the high floods (Table 37) of 1937, 1943, 1944, 1945, 1950, and the two high mean daily flow periods of 1949-1951 and 1943-1946 (Table 38), the period immediately after the cutoffs was one of unusually high water, when the river would have attempted to carve a high-water channel with long radius bends, such as the dredging program was attempting to build. This is also the period when the old (cutoff) bendways were still open and could convey high discharges during high flows. At the close of this period, a new levee profile was established. The recent (1973) flood proved the levee heights to be too low but only after a period of sustained low flows; 14 yearly flows between 1952 and 1972 were less than average. Figure 66 is a seven-year moving average of the mean daily flows, and the above wet and dry periods are clearly evident.

Shifts in rating curves have been used to indicate changes in channel capacities, but these are not as good an indication of channel regime changes as are specific gage records. Figures 67 through 73 are rating (stage versus discharge) curves for several of the main gages. These curves indicate a varied response of the river depending on location of the gage station in relation to work done on the river.

A simple test for stream channel regime can be made by plotting the stages for a constant discharge versus time in years (specific gage record). If the gage readings plot about a horizontal line, the river is in regime; but if the record shows a trend other than horizontal, the channel is changing its regime. An increase in stage would indicate probable aggradation, and a decrease would indicate degradation. Figures 74 through 80 are the specific gage records for the same gages as Figures 67 through 73. Trend lines can be drawn through the points that will indicate changes, not only in channel geometry (variations in direction of trend of high water and low water) but also the bed response (aggradation and degradation) to the levee, cutoff, and channelization. Figure 81 is a composite of the natural near bank-full flows. This figure gives a good picture of the reaction to: (a) the levee program over the entire river, (b) the cutoff program (1962 mile 341 to 678), and (c) the water diversion program at Red River.



MISSISSIPPI RIVER

POTAMOLOGY STUDIES

7-YEAR MOVING AVERAGE OF MEAN DAILY DISCHARGE FOR CALENDAR YEAR AT VICKSBURG

Figure 66

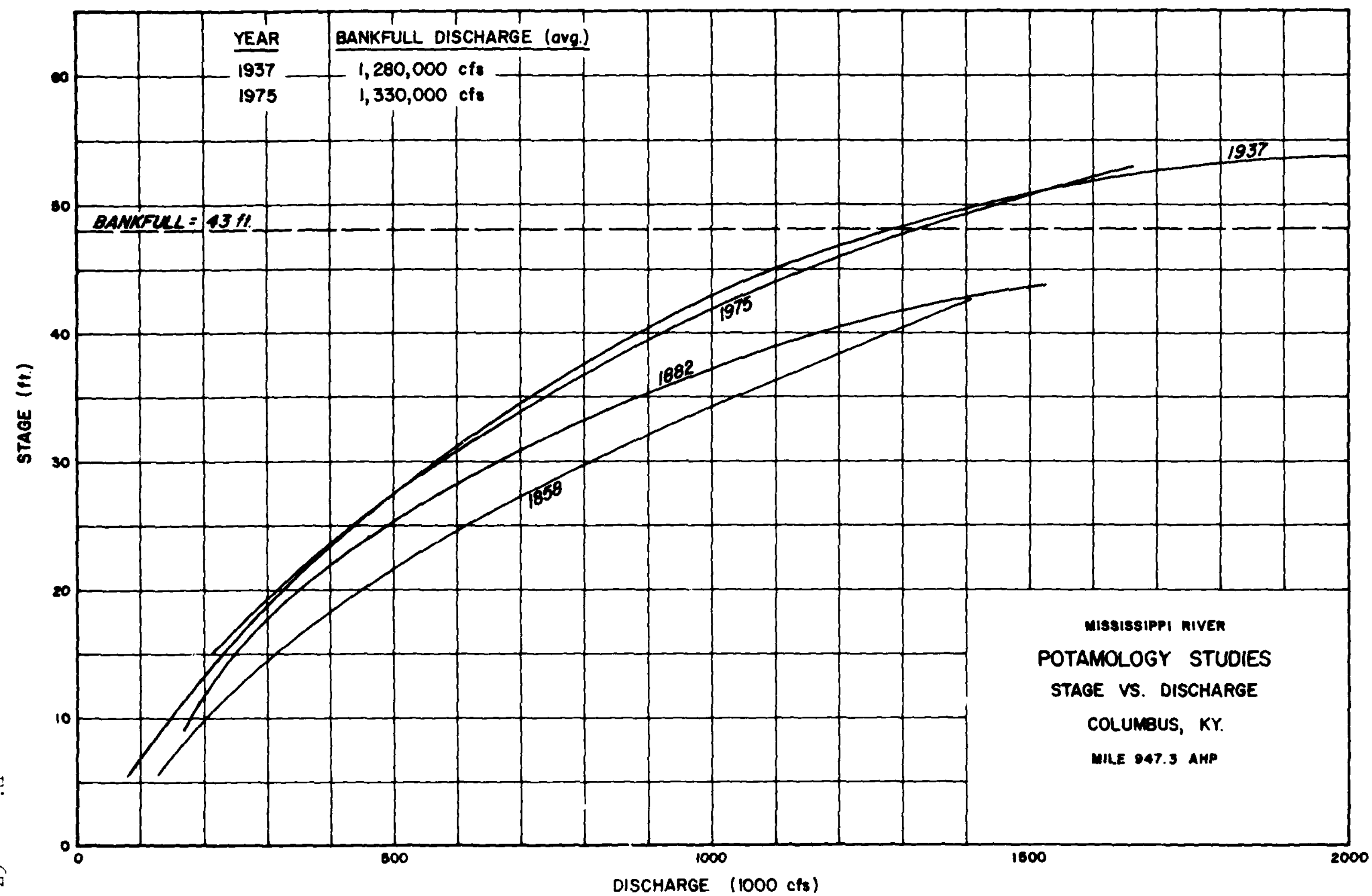

YEAR
BANKFULL DISCHARGE (avg.)
1937 1,280,000 cfs
1975 1,330,000 cfs
BANKFULL = 43 ft.
1937
1975
1882
1858
MISSISSIPPI RIVER
POTAMOLOGY STUDIES
STAGE VS. DISCHARGE
COLUMBUS, KY.
MILE 947.3 AHP
STAGE (ft.)
0
10
20
30
40
50
60
DISCHARGE (1000 cfs)
0
500
1000
1500
2000

Figure 67

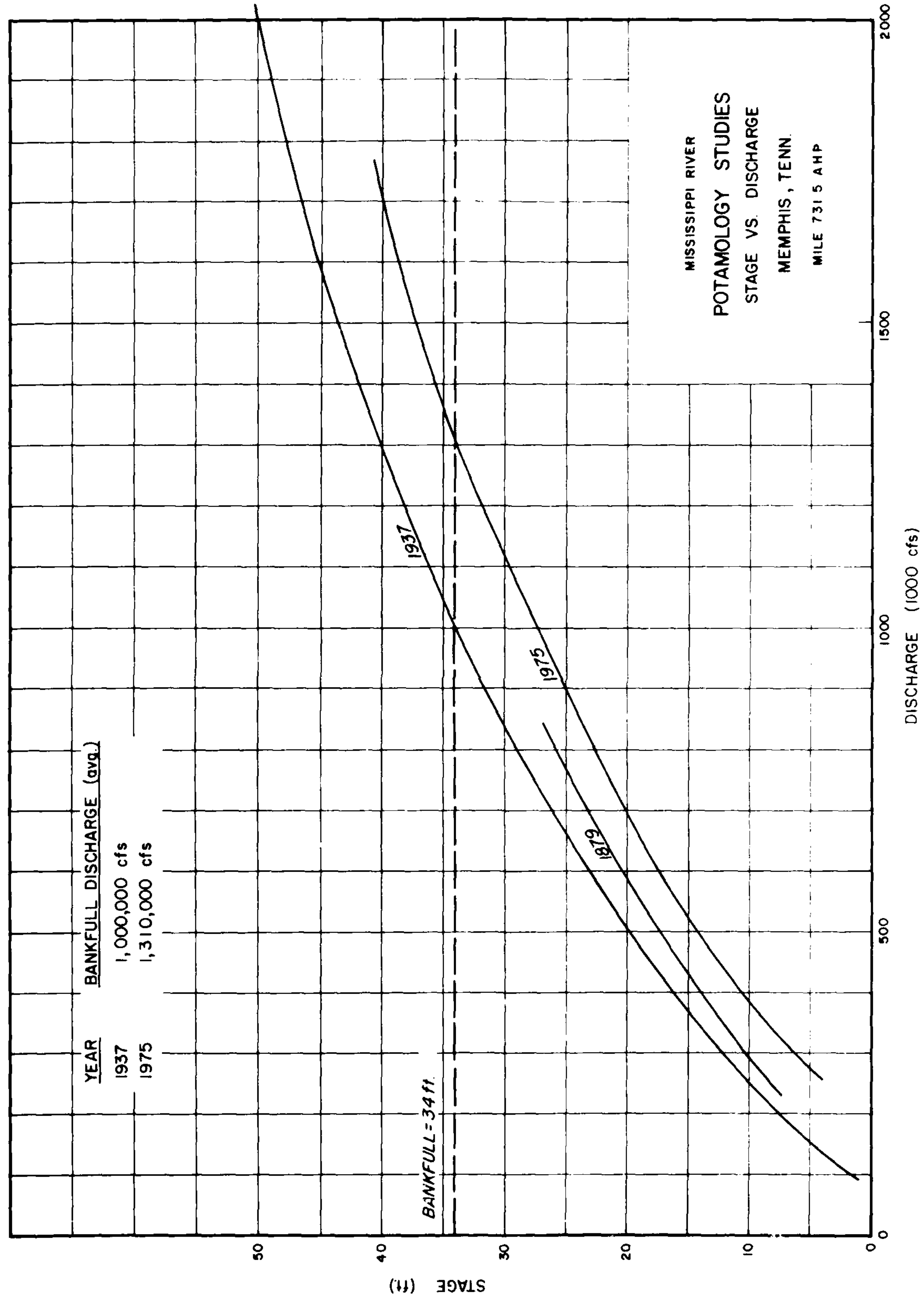

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
STAGE VS. DISCHARGE
MEMPHIS, TENN.
MILE 731.5 AHP
YEAR
BANKFULL DISCHARGE (avg.)
1937
1,000,000 cfs
1975
1,310,000 cfs
BANKFULL = 34 ft.
1937
1975
1879
STAGE (ft)
0
10
20
30
40
50
DISCHARGE (1000 cfs)
0
500
1000
1500
2000

Figure 68

AD-A116 595 ARMY ENGINEER DISTRICT VICKSBURG MISS F/G 13/2
MAN-MADE CUTOFFS ON THE LOWER MISSISSIPPI RIVER, CONCEPTION, CO--ETC(U)
MAR 77 B R WINKLEY
UNCLASSIFIED 300-2 NL

3 OF 3
AD A
116595

END
DATE
FILMED
08-82
DTIC

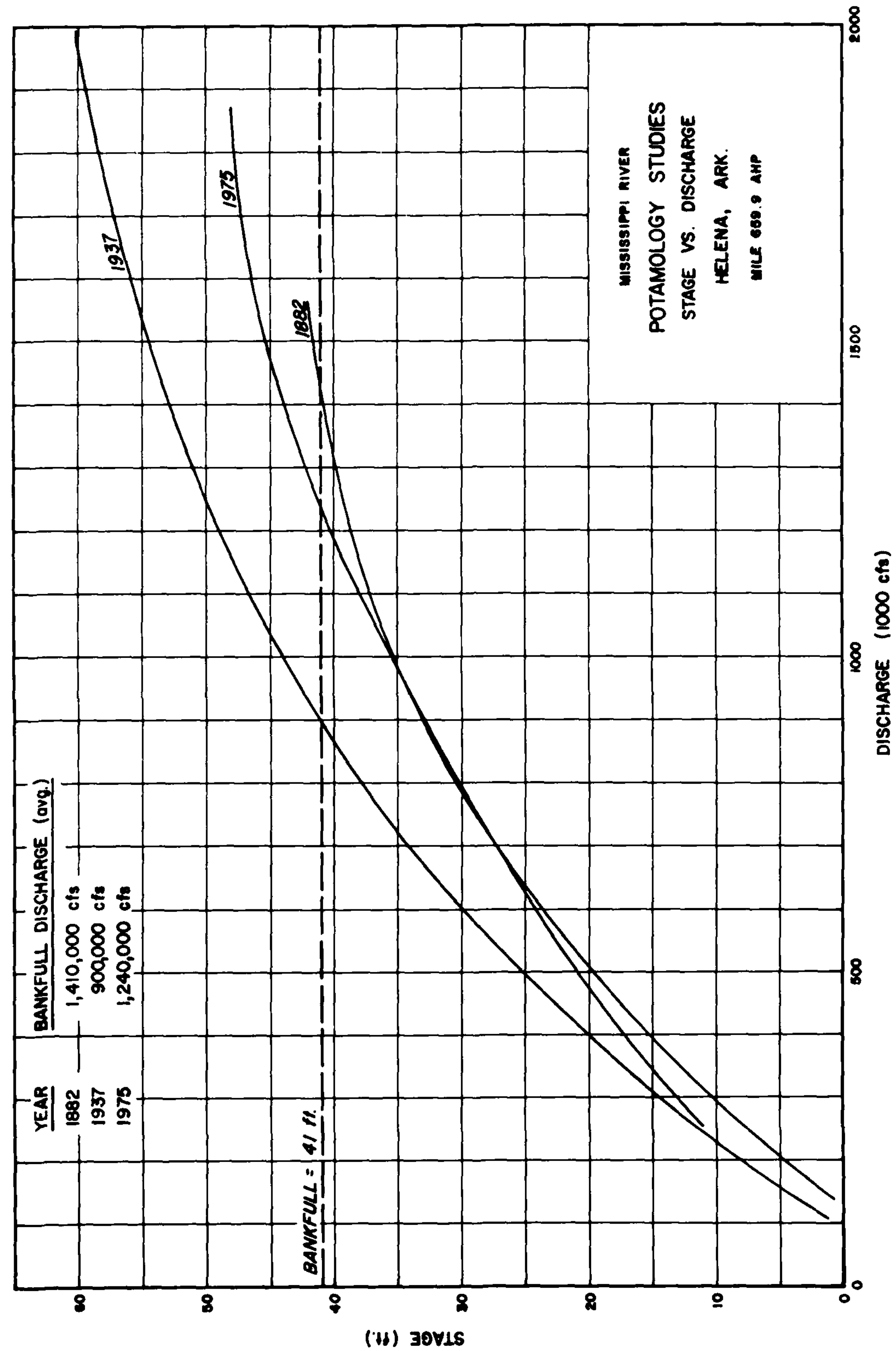

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
STAGE VS. DISCHARGE
HELENA, ARK.
MILE 659.9 AHP
YEAR
BANKFULL DISCHARGE (avg.)
1882 1,410,000 cfs
1937 900,000 cfs
1975 1,240,000 cfs
BANKFULL = 41 ft.
1937
1975
1882
DISCHARGE (1000 cfs)
STAGE (ft.)
0
500
1000
1500
2000
10
20
30
40
50
60

Figure 69

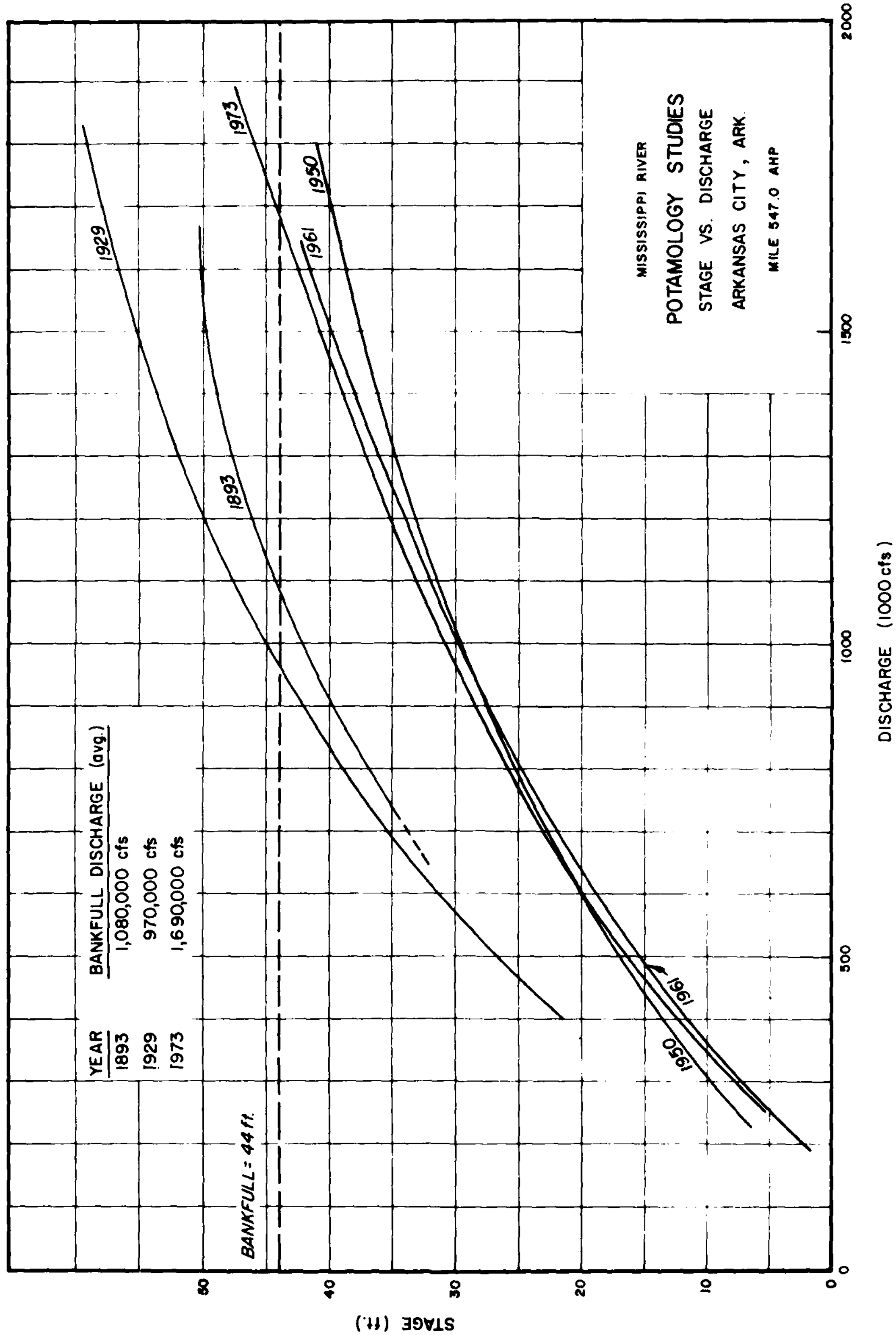

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
STAGE VS. DISCHARGE
ARKANSAS CITY, ARK.
MILE 547.0 AHP
YEAR
BANKFULL DISCHARGE (avg.)
1893 1,080,000 cfs
1929 970,000 cfs
1973 1,690,000 cfs
BANKFULL: 44 ft.
1929
1893
1973
1961
1950
STAGE (ft.)
0
10
20
30
40
50
DISCHARGE (1000 cfs)
0
500
1000
1500
2000

Figure 70

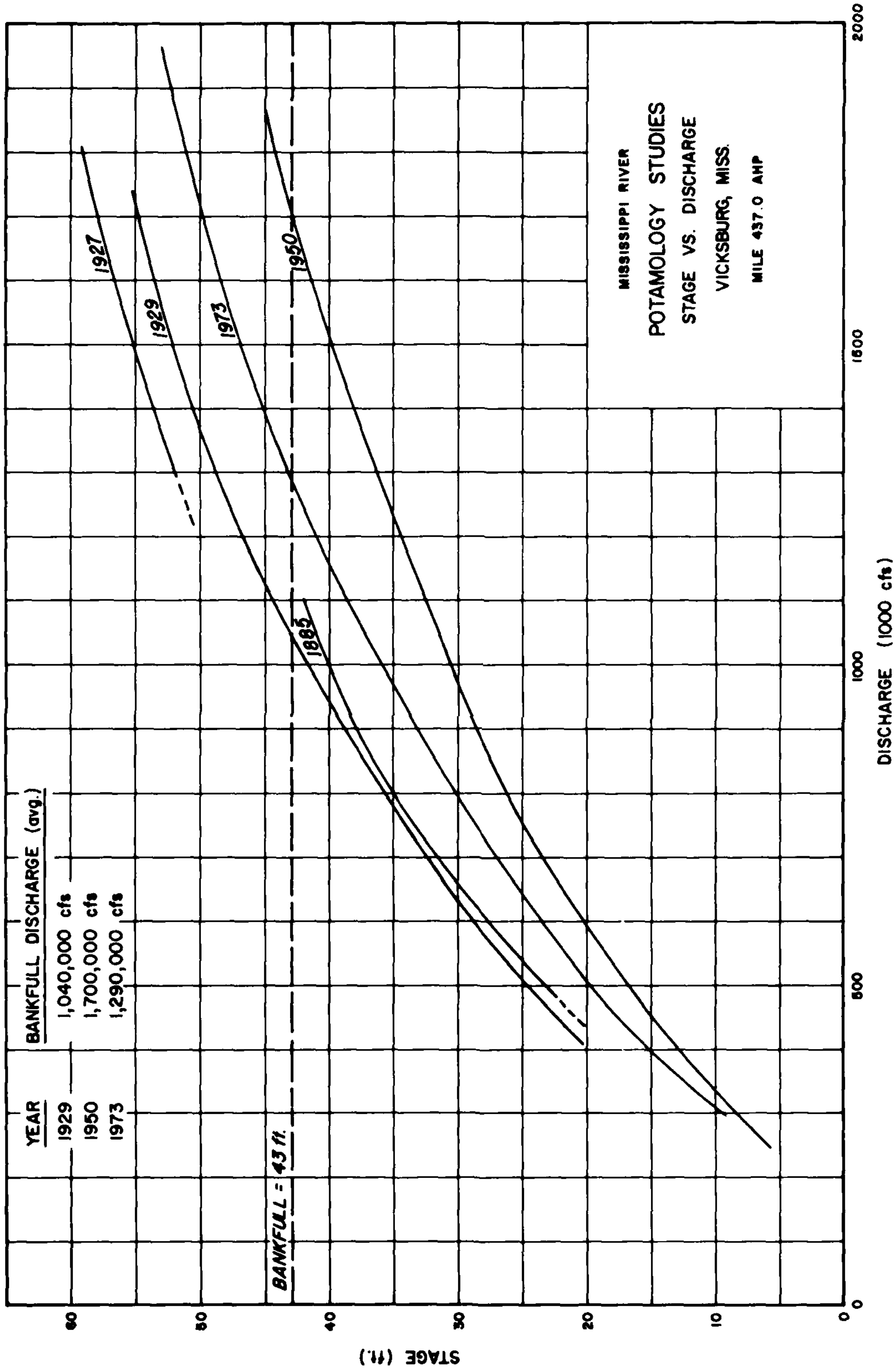

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
STAGE VS. DISCHARGE
VICKSBURG, MISS.
MILE 437.0 AHP
YEAR
1929
1950
1973
BANKFULL DISCHARGE (avg.)
1,040,000 cfs
1,700,000 cfs
1,290,000 cfs
BANKFULL = 43 ft.
1927
1929
1973
1950
1885
STAGE (ft.)
DISCHARGE (1000 cfs)
0
10
20
30
40
50
60
500
1000
1500
2000

Figure 71

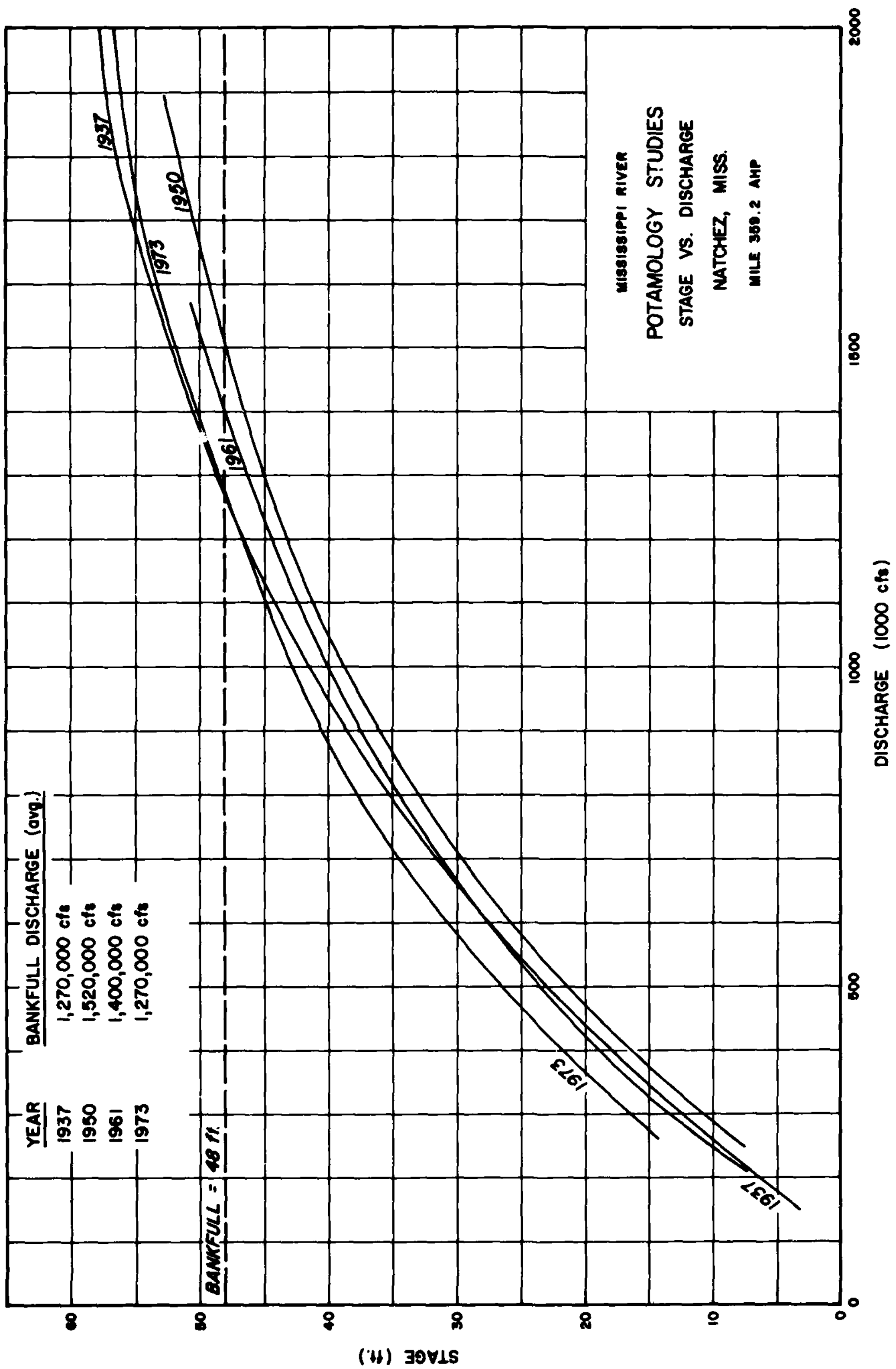

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
STAGE VS. DISCHARGE
NATCHEZ, MISS.
MILE 359.2 AHP
YEAR
1937
1950
1961
1973
BANKFULL DISCHARGE (avg.)
1,270,000 cfs
1,520,000 cfs
1,400,000 cfs
1,270,000 cfs
BANKFULL = 48 ft.
1937
1950
1961
1973
STAGE (ft.)
DISCHARGE (1000 cfs)
0
10
20
30
40
50
60
0
500
1000
1500
2000

Figure 72

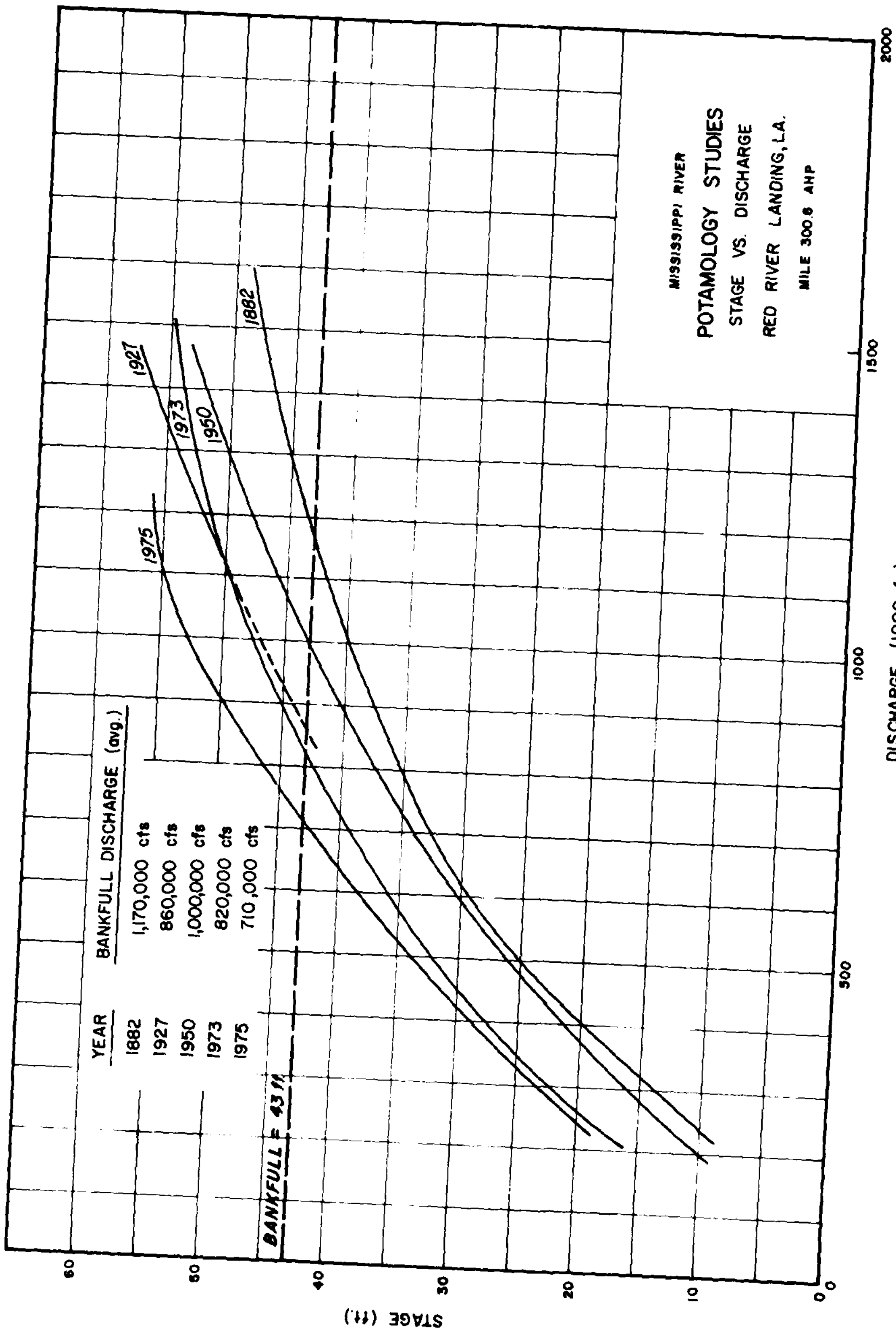
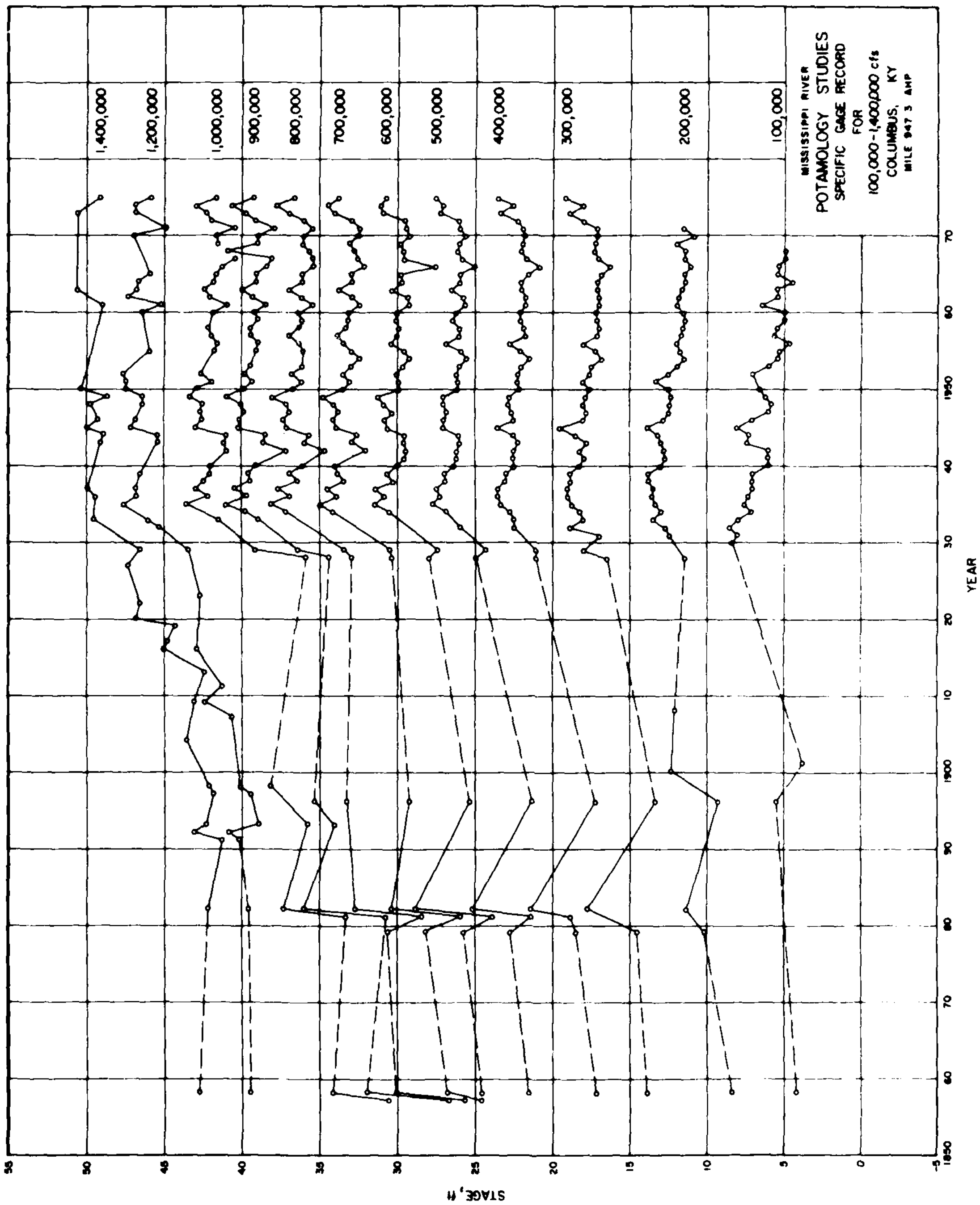

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
STAGE VS. DISCHARGE
RED RIVER LANDING, LA.
MILE 300.6 AHP
YEAR
BANKFULL DISCHARGE (avg.)
1882 1,170,000 cfs
1927 860,000 cfs
1950 1,000,000 cfs
1973 820,000 cfs
1975 710,000 cfs
BANKFULL = 43 ft
1882
1927
1973
1950
1975
STAGE (ft)
DISCHARGE (1000cfs)
0
10
20
30
40
50
60
0
500
1000
1500
2000

Figure 73



MISSISSIPPI RIVER
POTAMOLOGY STUDIES
SPECIFIC GAGE RECORD
FOR
100,000-1,400,000 cfs
COLUMBUS, KY
MILE 947.3 AHP
1,400,000
1,200,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
YEAR
STAGE, ft

Figure 74

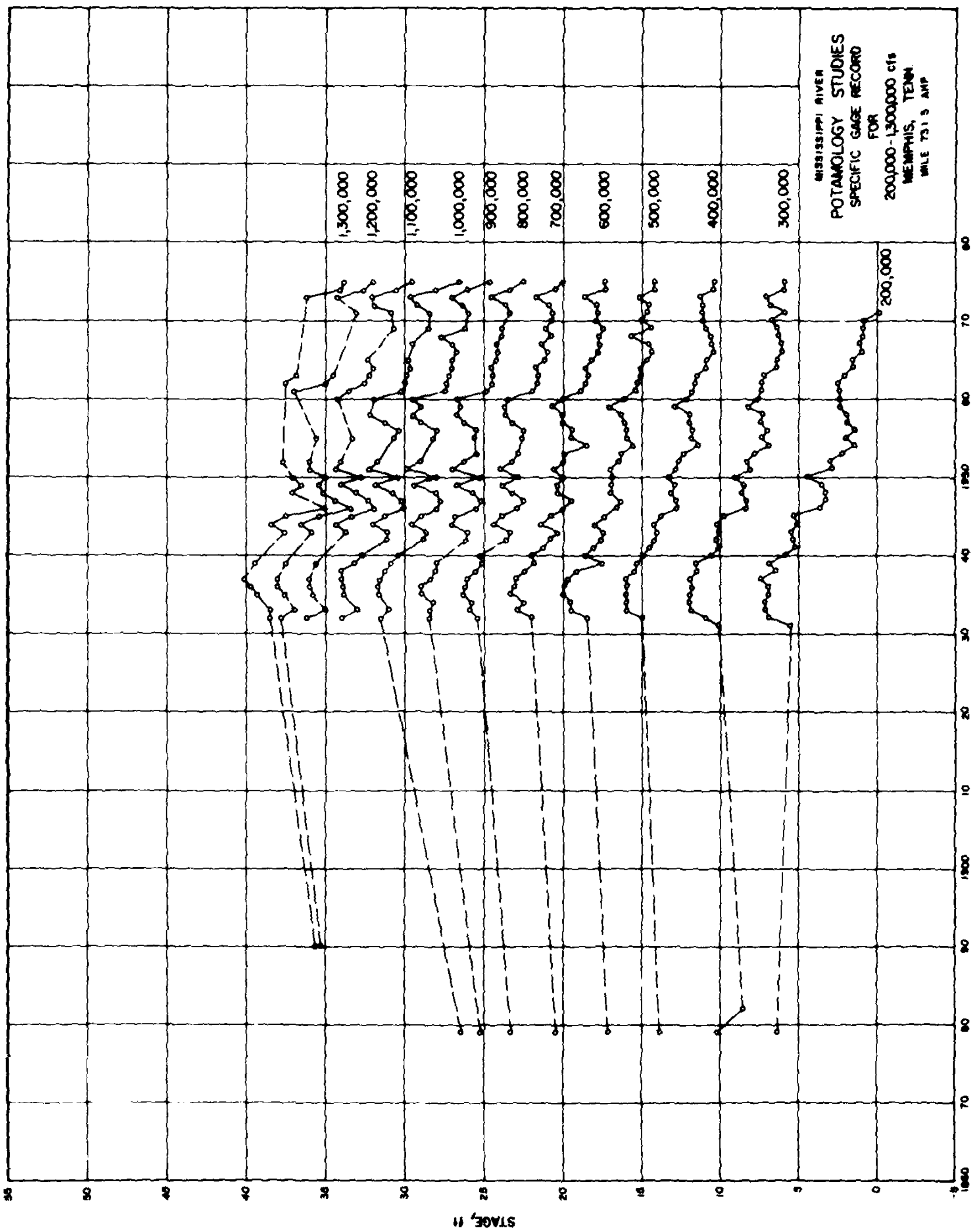

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
SPECIFIC GAGE RECORD
FOR
200,000-1,300,000 cfs
MEMPHIS, TENN.
MILE 731.5 AHP
1,300,000
1,200,000
1,100,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
YEAR
STAGE, ft

Figure 75

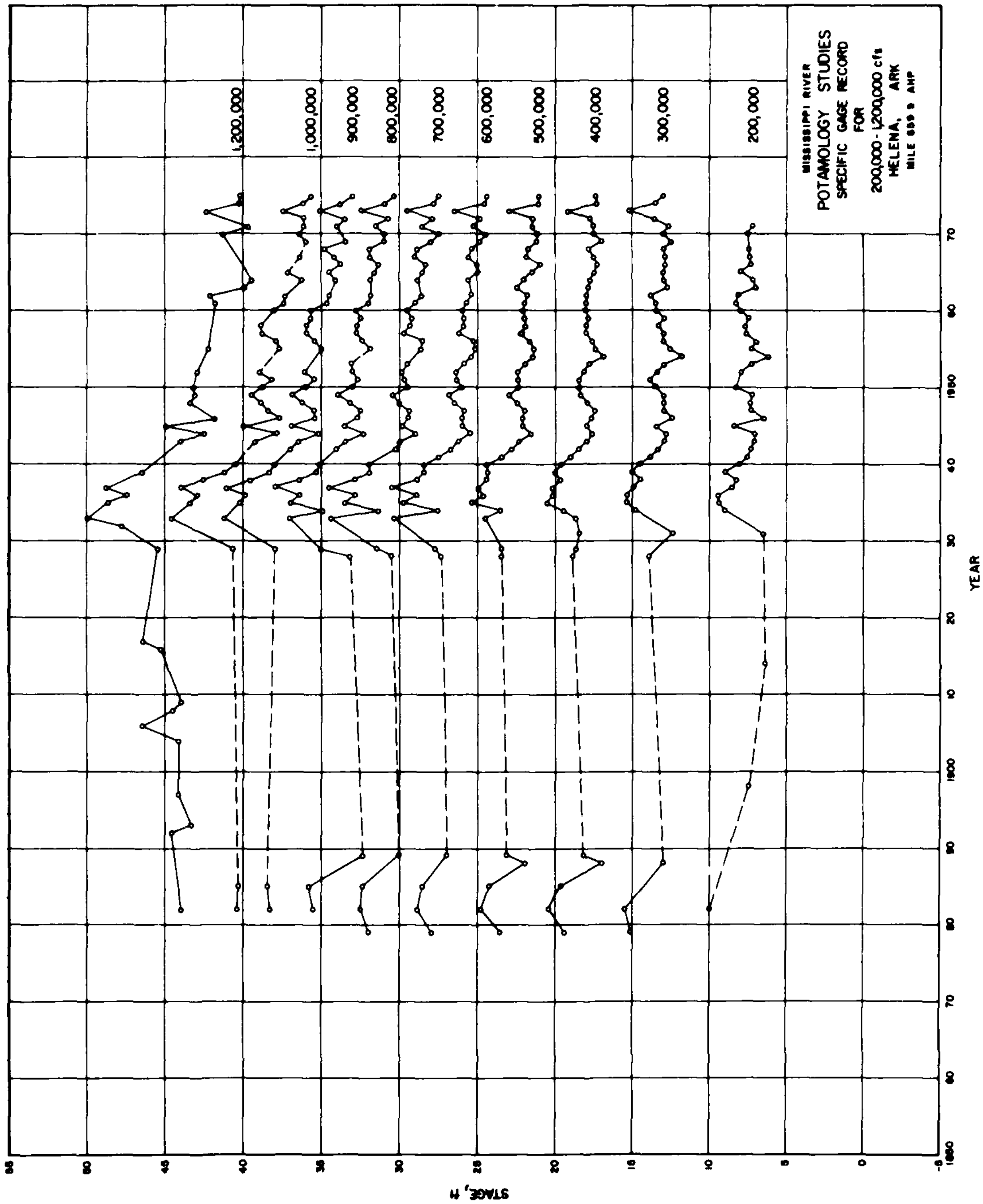

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
SPECIFIC GAGE RECORD
FOR
200,000-1,200,000 cfs
HELENA, ARK
1,200,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
STAGE, ft
YEAR

Figure 76

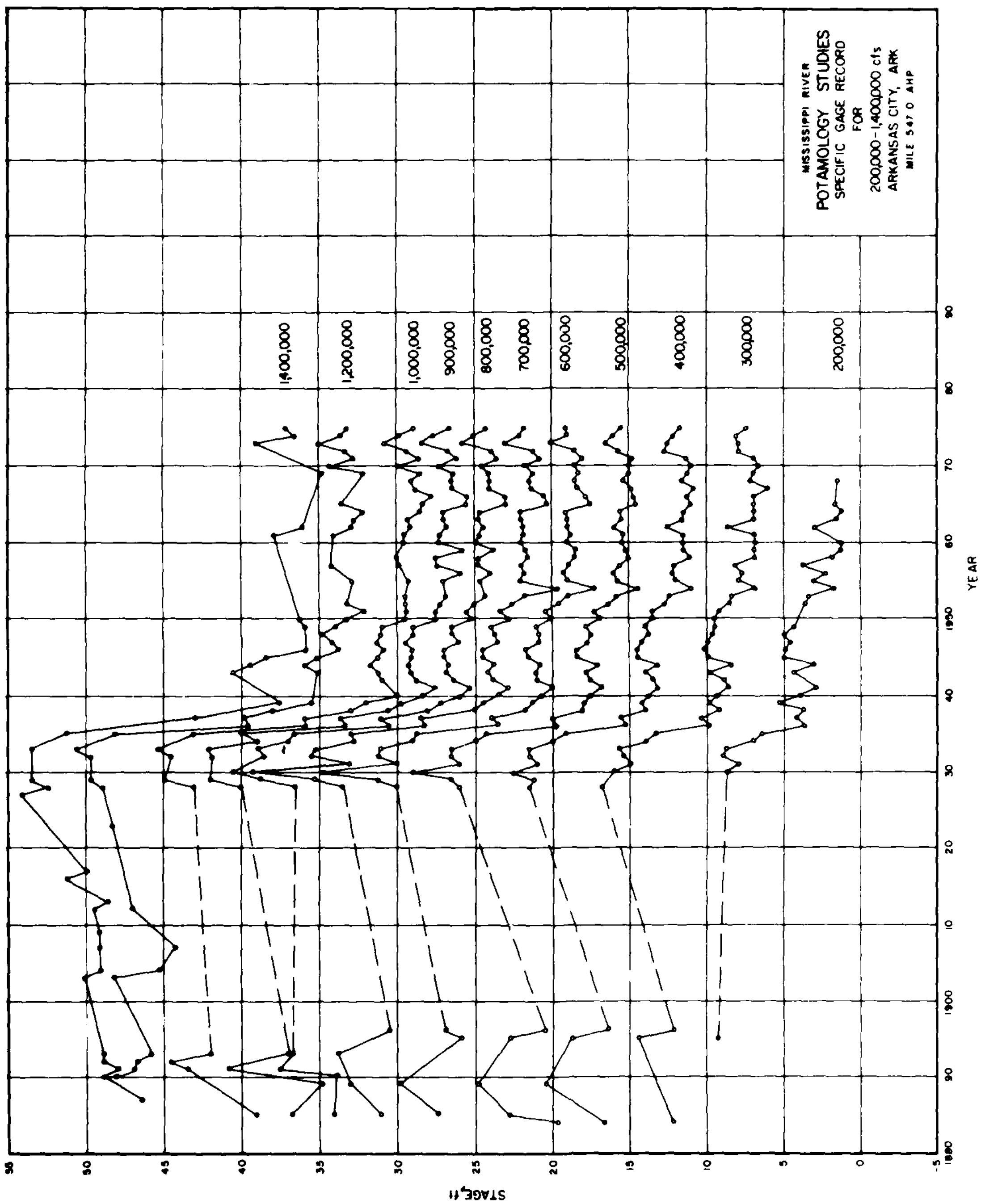

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
SPECIFIC GAGE RECORD
FOR
200,000-1,400,000 cfs
ARKANSAS CITY, ARK
MILE 547.0 AHP
1,400,000
1,200,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
YEAR
STAGE, ft

Figure 77

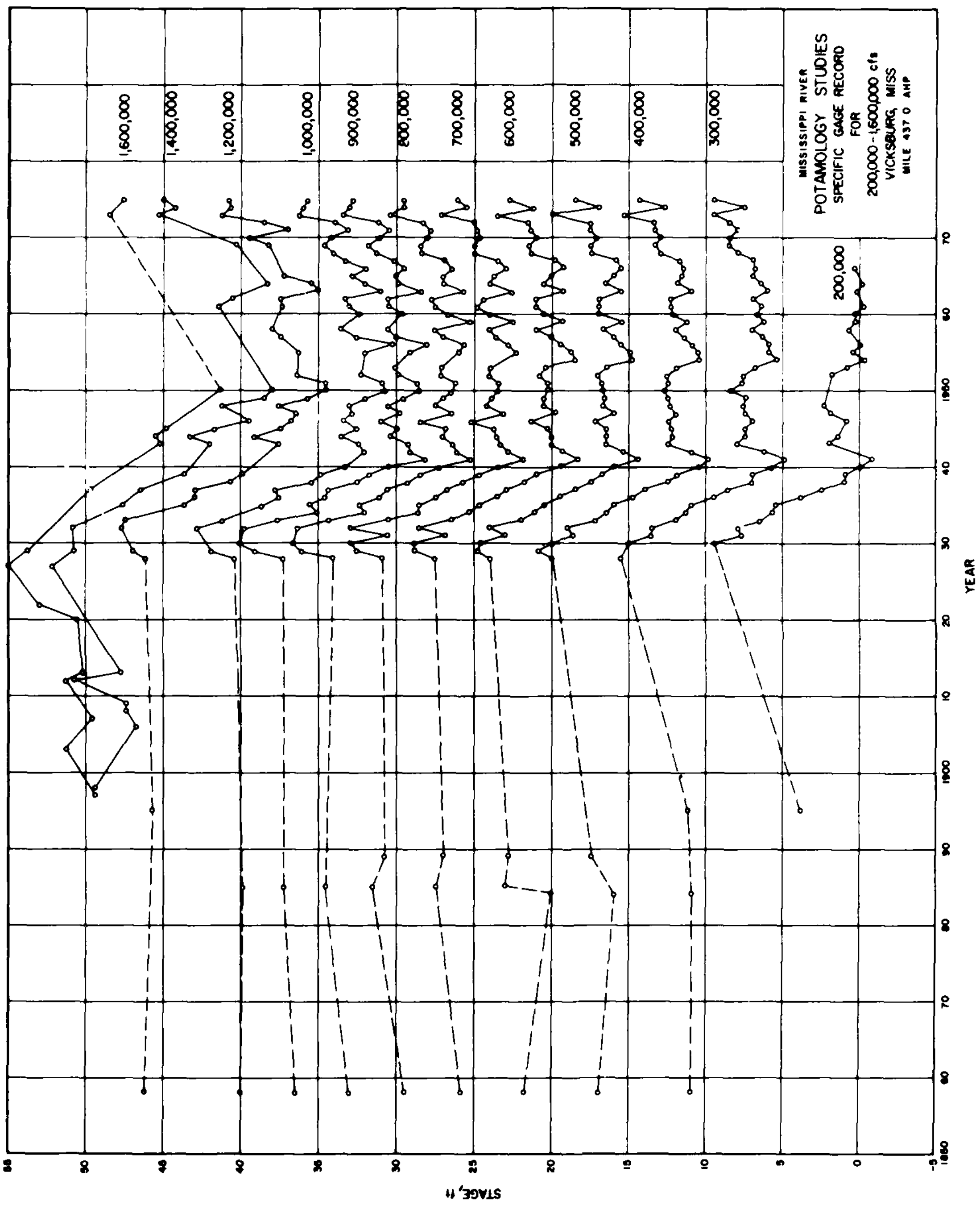

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
SPECIFIC GAGE RECORD
FOR
200,000-1,600,000 cfs
VICKSBURG, MISS
MILE 437.0 AHP
1,600,000
1,400,000
1,200,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
YEAR
STAGE, ft

Figure 78

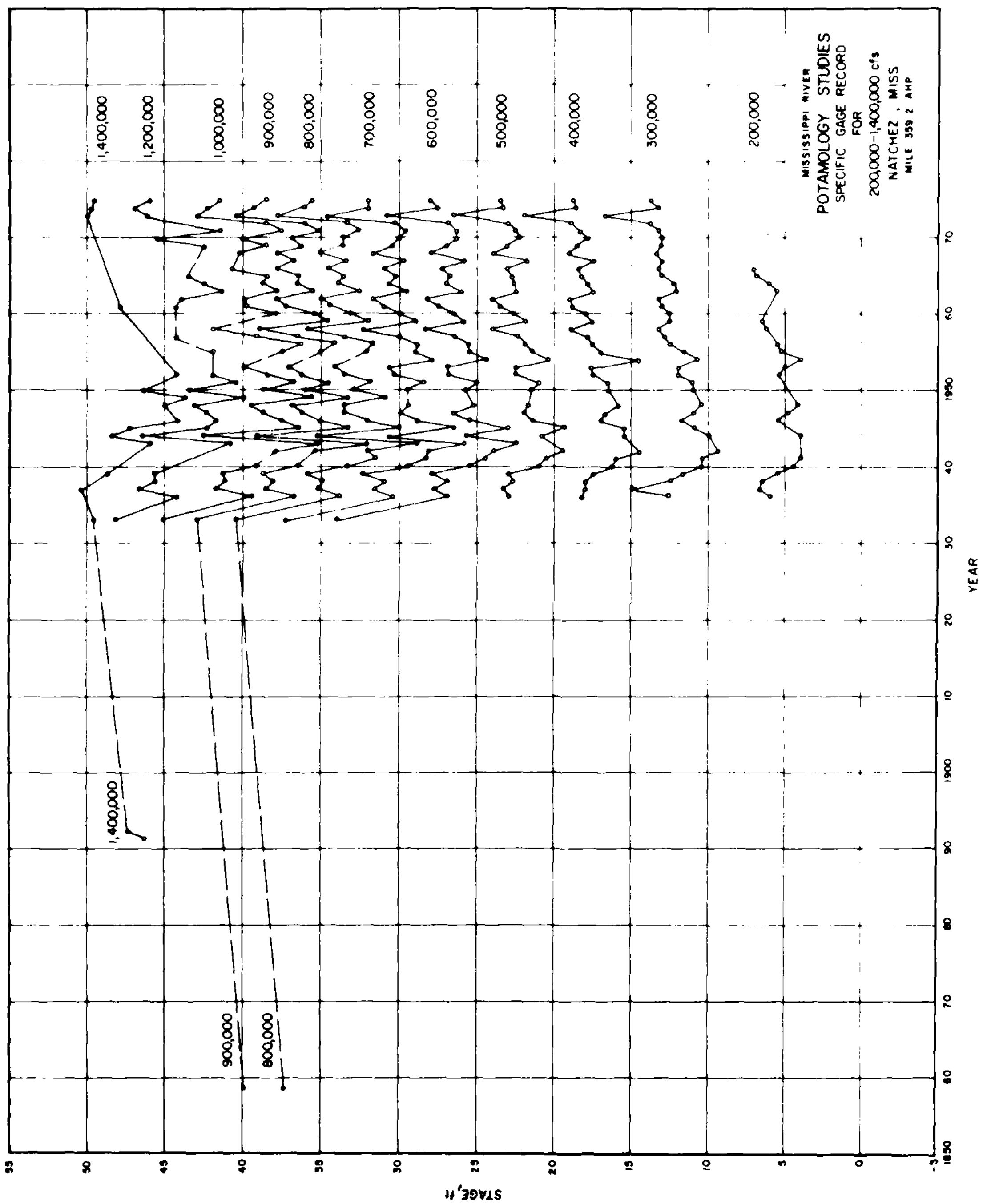
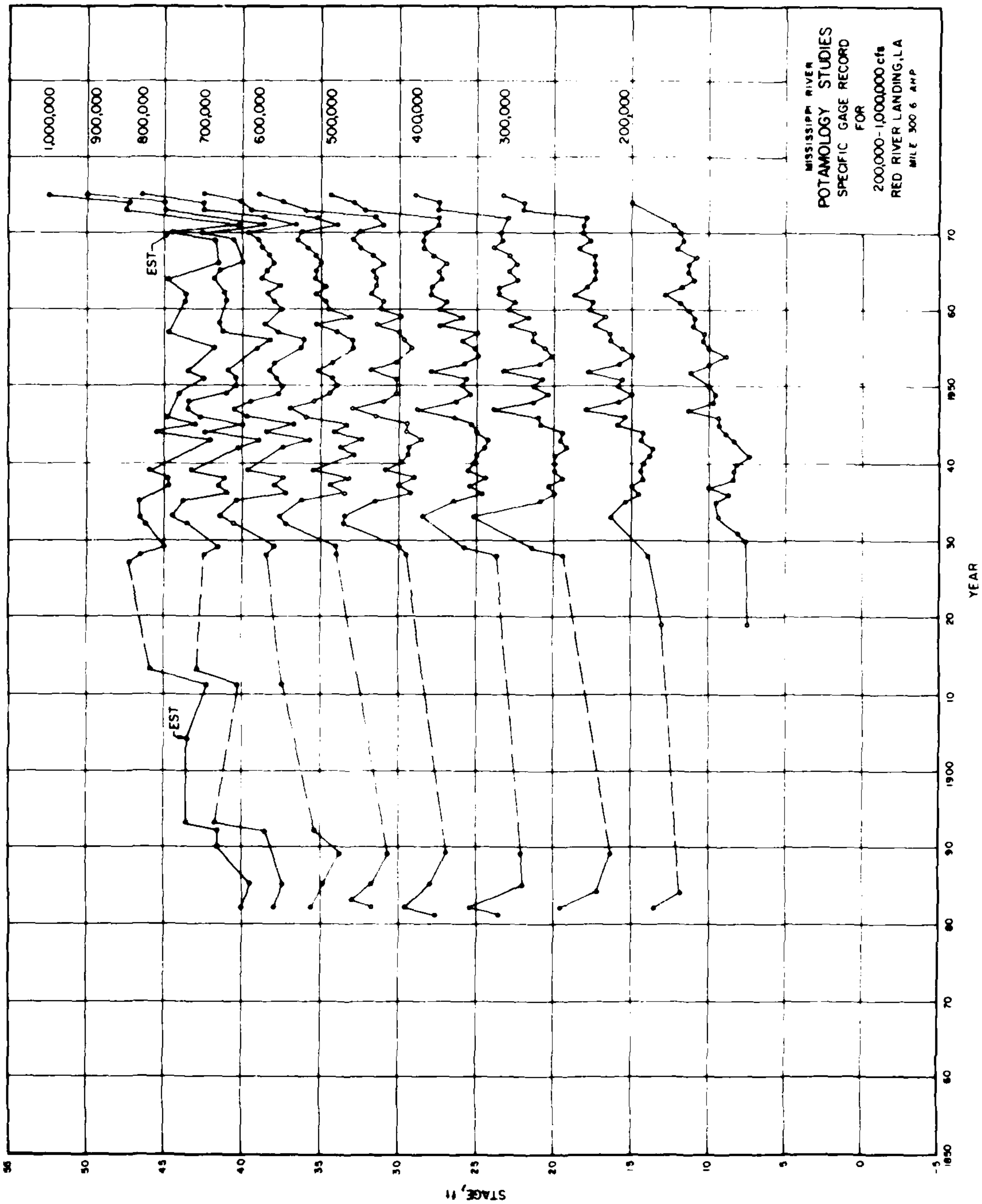
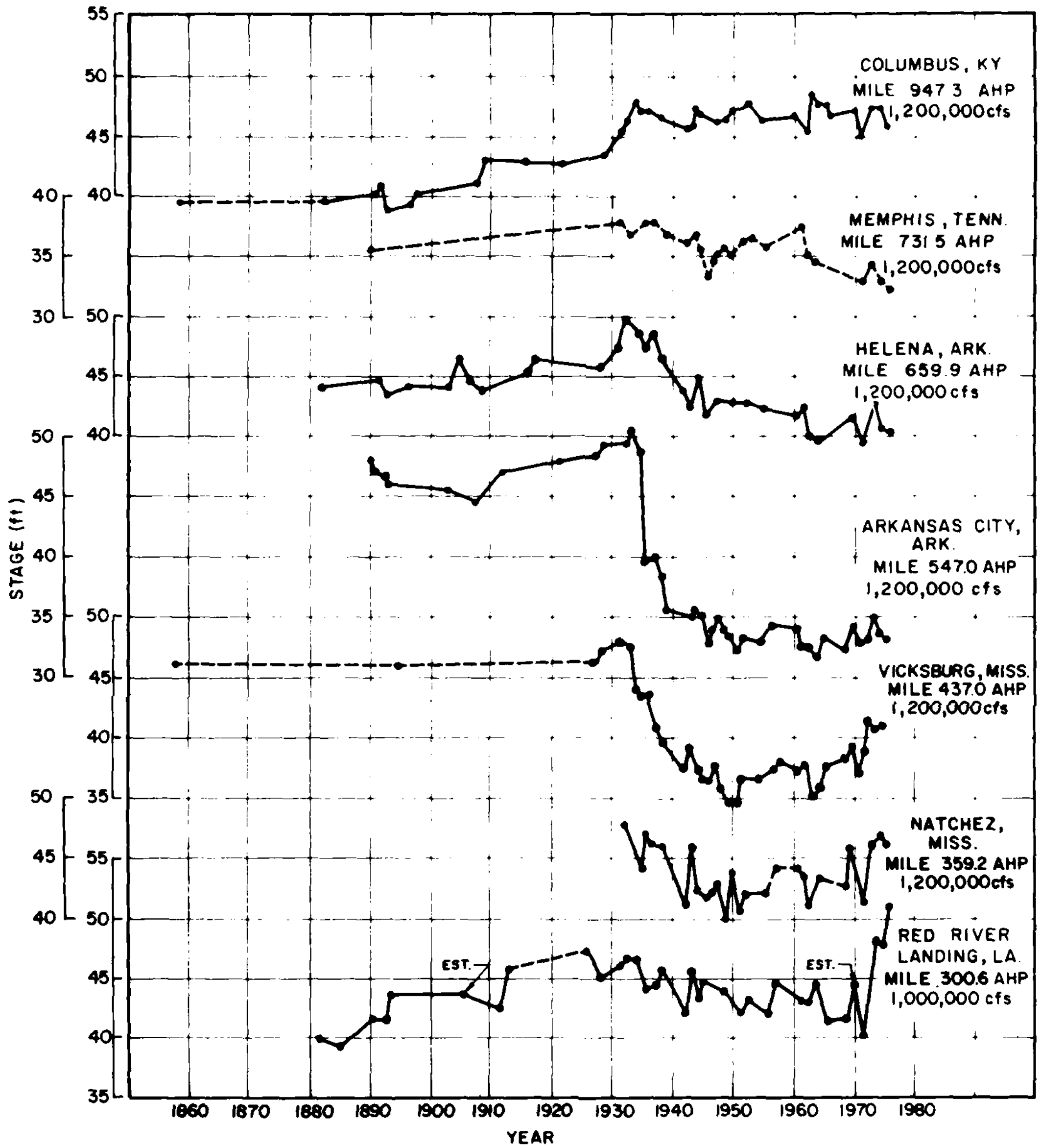

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
SPECIFIC GAGE RECORD
FOR
200,000-1,400,000 cfs
NATCHEZ, MISS
MILE 359.2 AHP
1,400,000
1,200,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
STAGE, ft
YEAR

Figure 79



MISSISSIPPI RIVER
POTAMOLOGY STUDIES
SPECIFIC GAGE RECORD
FOR
200,000-1,000,000 cfs
RED RIVER LANDING, LA
MILE 300.6 AHP
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
EST
EST
YEAR
STAGE, ft

Figure 80



MISSISSIPPI RIVER

POTAMOLOGY STUDIES

SPECIFIC GAGE RECORDS

FOR NEAR NATURAL BANK-FULL STAGES AT VARIOUS GAGES

Figure 81

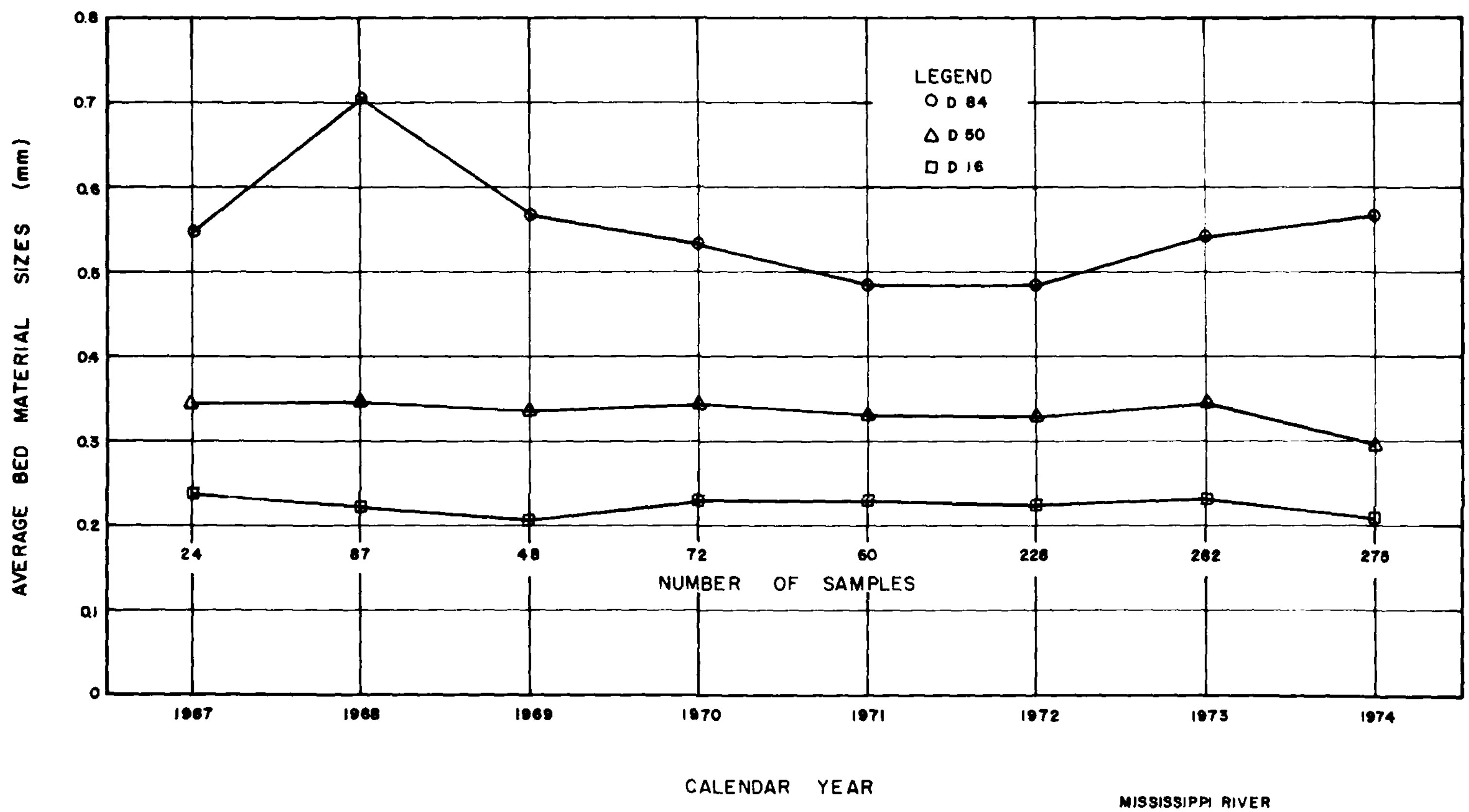
9.06 <u>Sediments</u>. In his report, Robbins[15] presents all sediment data available for the VXD; therefore, only broad changes in sediment patterns will be considered in the following paragraphs.

The downvalley movement of sediments has been altered by the cutoff program, the increased dredging program (Mississippi River dredge spoils are returned to the river), and the bank stabilization program. When the Lower Mississippi River (Cairo, Illinois, to the Gulf of Mexico) was allowed to meander unrestricted, the sediment movement was from bank and bed to bar formation. The bars were built up to valley profile and abandoned until cut into by the migrating river at some distant time. Thus, sediment movement was more lateral across the valley than down the valley, and movement of the coarse sediments toward the Gulf was slow. Today, the plan geometry of the river is fixed at a steeper slope (shortened length), and the movement of coarse sediments is more pronounced because the bars now offer only a short temporary storage location and each high water moves the coarse sediments down valley at an ever-increasing rate. This creates problems in the lower part of the river where the slopes are too flat to move these coarse sediments. In addition, the water diversion at Old River creates a situation causing sediments to deposit in both channels.

This downvalley bed sediment movement is seen in recent surveys (Figures 82 through 84). These figures were taken from a report by Robbins[15] in which he comments on the suspended sediment data:

> Comparison of the data for the periods 1929-31 and 1967-74 indicates that the suspended sediment concentrations have decreased since 1931 by roughly 40 percent. Much of this decrease could be due largely to the bank stabilization program. The bank revetment construction history for the Vicksburg District is shown in Figure 51 which indicates that the major part of the work has been done since 1945. Figure 85 shows the caving bank history for the Vicksburg District for three periods of record. Recent stabilization has eliminated most of the bank caving on the lower Mississippi River.

Many of the divided flow and navigation and flood control problems have occurred in the past 10-20 years. After the cutoff program and



MISSISSIPPI RIVER

POTAMOLOGY STUDIES

VARIATION IN AVERAGE BED MATERIAL SIZES
AT ARKANSAS CITY DISCHARGE RANGE

MILE 565.9 AHP

Figure 82

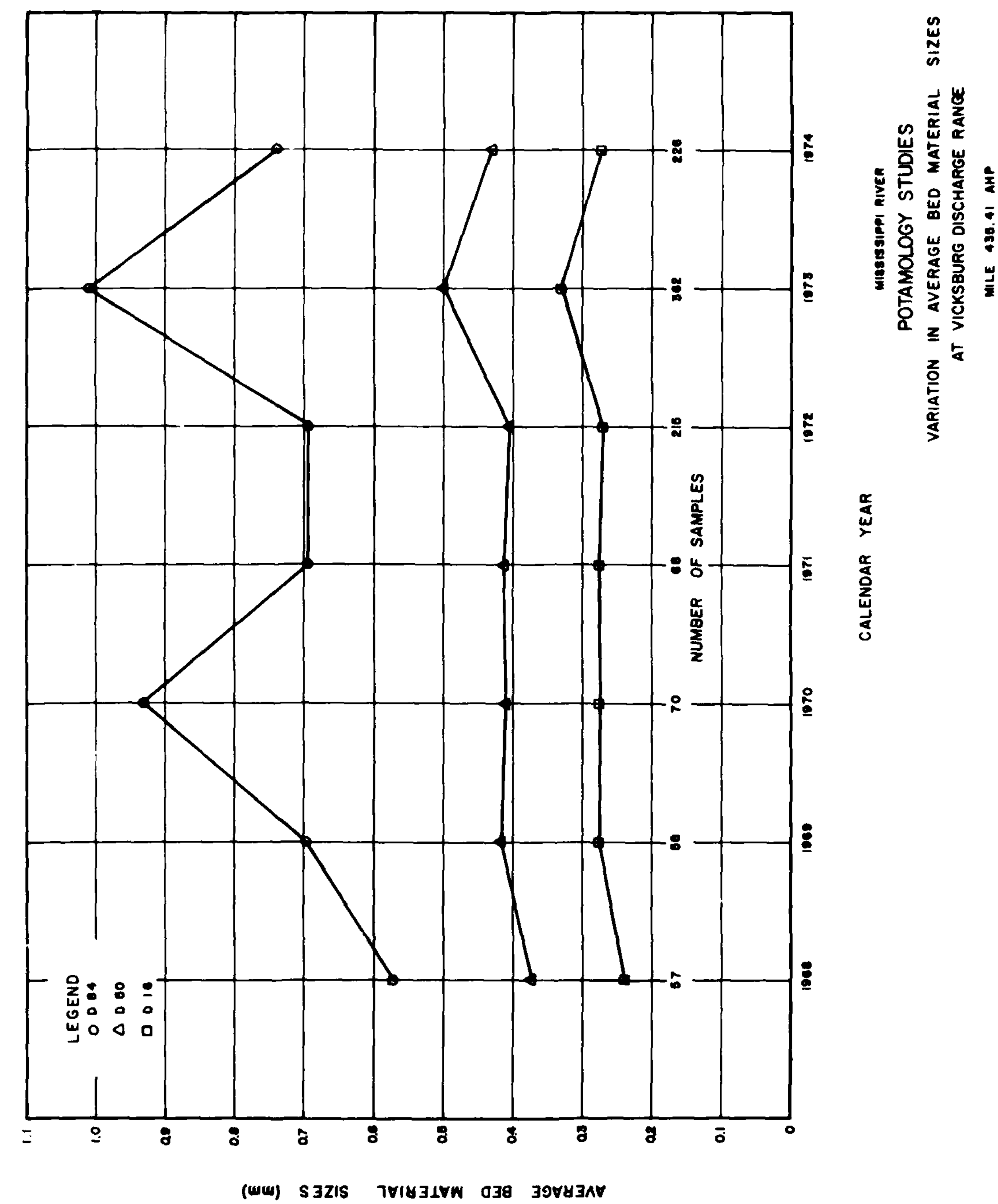
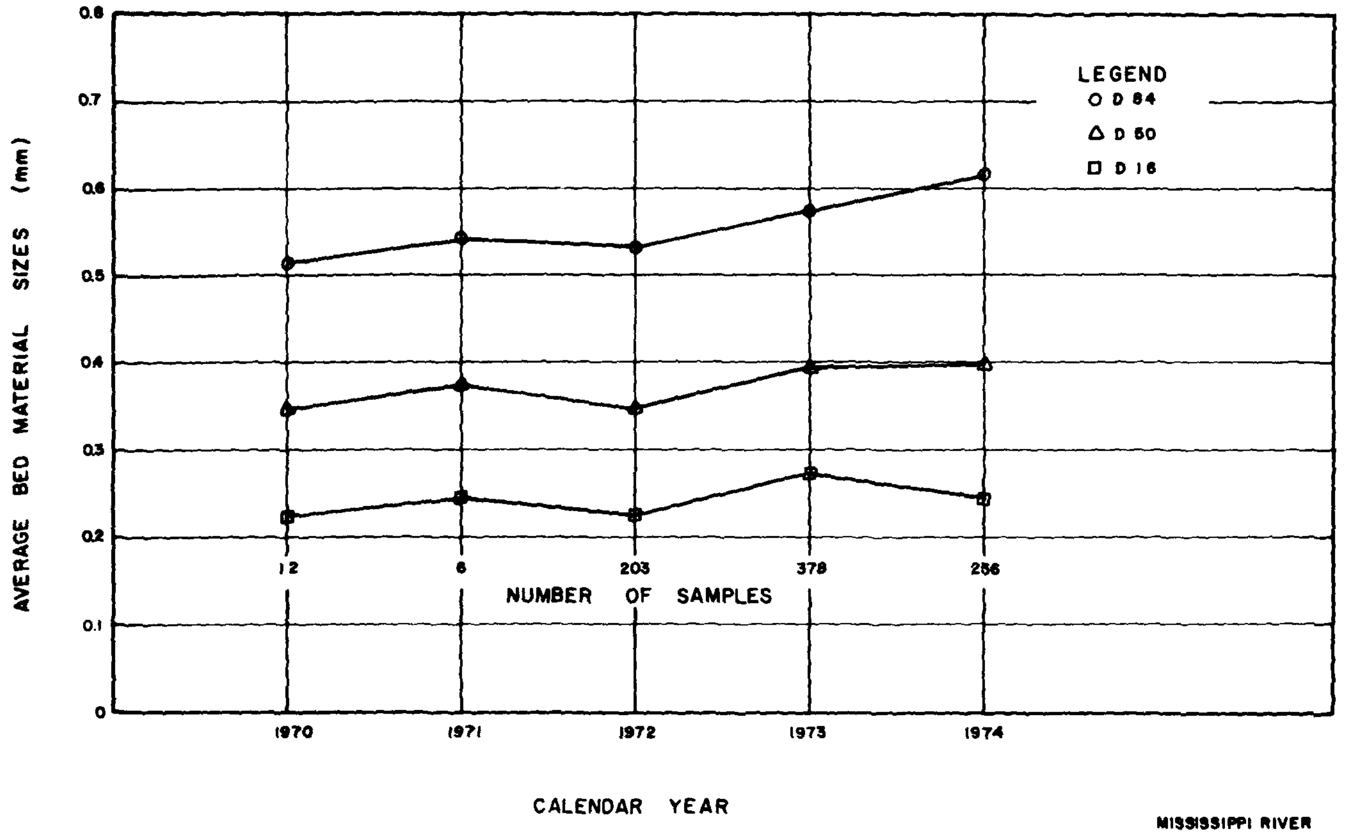

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
VARIATION IN AVERAGE BED MATERIAL SIZES
AT VICKSBURG DISCHARGE RANGE
MILE 435.41 AHP
LEGEND
O D 84
Δ D 50
□ D 16
AVERAGE BED MATERIAL SIZES (mm)
NUMBER OF SAMPLES
CALENDAR YEAR
57
56
70
68
215
362
228
1968
1969
1970
1971
1972
1973
1974
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1

Figure 83



MISSISSIPPI RIVER

POTAMOLOGY STUDIES

VARIATION IN AVERAGE BED MATERIAL SIZES AT NATCHEZ DISCHARGE RANGE

MILE 362.34 AHP

Figure 84

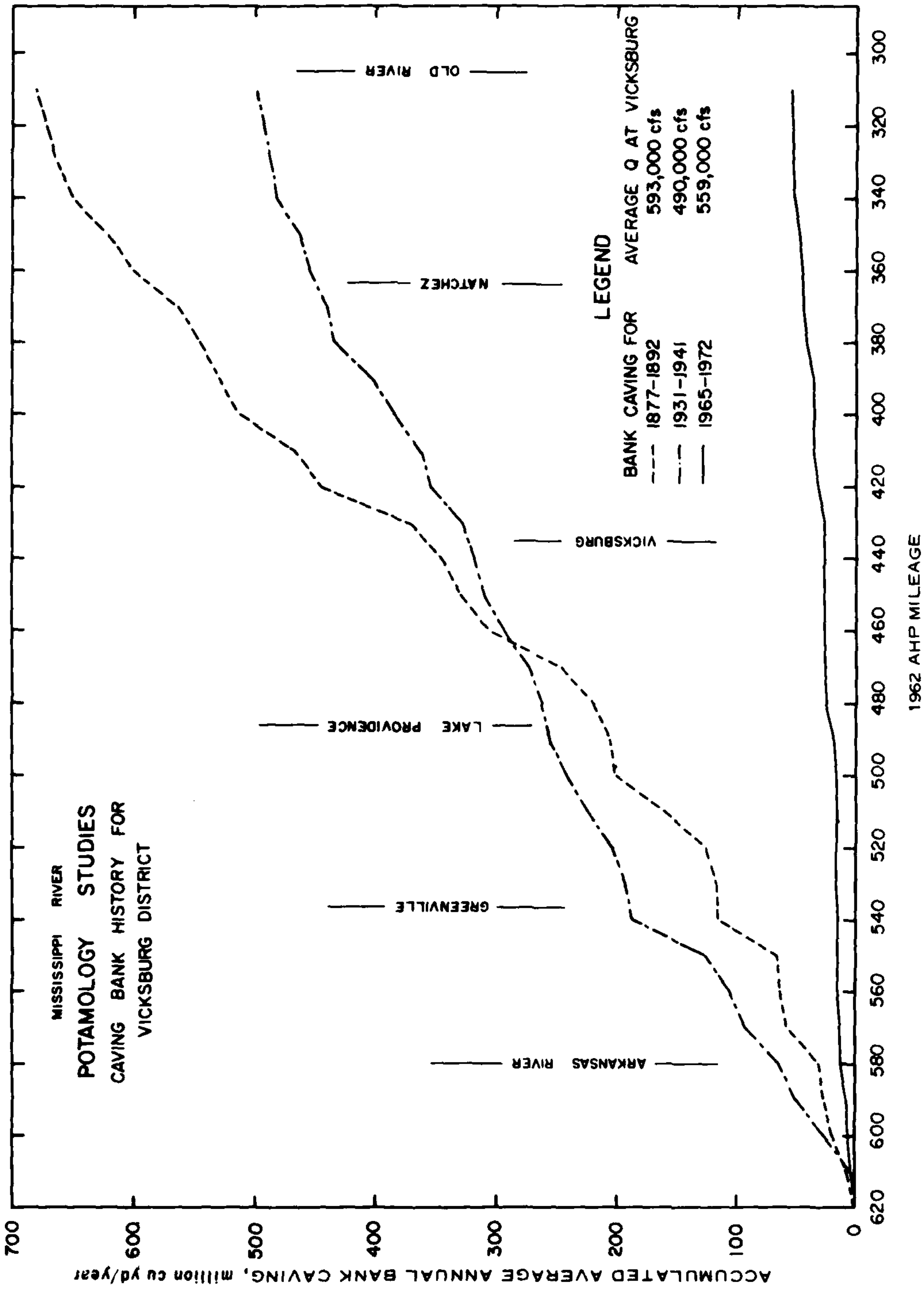

MISSISSIPPI RIVER
POTAMOLOGY STUDIES
CAVING BANK HISTORY FOR
VICKSBURG DISTRICT
LEGEND
BANK CAVING FOR
AVERAGE Q AT VICKSBURG
1877-1892
593,000 cfs
1931-1941
490,000 cfs
1965-1972
559,000 cfs
OLD RIVER
NATCHEZ
VICKSBURG
LAKE PROVIDENCE
GREENVILLE
ARKANSAS RIVER
300
320
340
360
380
400
420
440
460
480
500
520
540
560
580
600
620
1962 AHP MILEAGE
0
100
200
300
400
500
600
700
ACCUMULATED AVERAGE ANNUAL BANK CAVING, million cu yd/year

Figure 85

the realignment program, the river had two channels in which to store and to transport high flows. These back channels also provided a huge storage area for the coarser bed sediments. Now these back channels have almost filled and have become vegetated. Adequate storage and conveyance channels for floods no longer exist and bed sediment storage has decreased. The result seems to be creating a braided type stream with less flow efficiency and an increased movement of coarse sediment.

SECTION 10. CONCLUSIONS AND RECOMMENDATIONS

There is no doubt that the cutoff program on the Mississippi River did lower flow lines in the reach of the cutoffs and in the upstream reach. Furthermore, when the balance of the regime of an alluvial river has been upset, the river will react and attempt to rebalance its hydraulics and its geometry to the conditions of discharge and sediments that prevail. Recent reactions have indicated that the river is not behaving as hoped and that it is attempting to rebalance its regime within the confines of levees, outlets (both opened and closed), steeper slopes, bank revetment and training dikes, and variations in sediment loads. One unanswered question is, With the restrictions imposed, can adequate navigation and flood control be regained? The other unanswered question is, What could have been done to improve navigation and flood control other than cutoffs and the subsequent channel "stabilization"?

The following paragraphs apply to the Lower Mississippi River, but within the restrictions of type and size of the hydrograph, type and availability of the sediments, and the size and shape of the drainage basin, these statements can be applied to most rivers.

No cutoff should be made on any river until a complete geomorphic history has been assembled and analyzed. A stability factor can be gained by noting the amount of bar building and bank caving. The more bar movement and bank caving evident the closer the river is to becoming a braided type river with complete instability. A well-vegetated river with comparable size trees on both banks indicates a very stable river. A very sinuous stream with well-vegetated banks or a braided stream with vegetated permanent islands is probably residual of a sediment movement that no longer exists. Minimum sediment movement, no bank caving, and flat gradients are indicative of stable rivers that will react very slowly to imposed changes. Steep gradients, bank caving, and exposed bars are indicative of unstable conditions. Also, the time and the magnitude of a reaction are directly related to the energy gradient of the system.

The Lower Mississippi River was an unstable stream prior to the

cutoff program as a result of the 1811-1812 earthquake and the levee program. The time required to recover from a single cutoff is an aid to determining the time-slope factor. Under historic conditions (which were transitive in reaction to the earthquake and levees), it took the Lower Mississippi River from 30 to 80 years to recover from a single natural cutoff. Recovery here means regaining widths, depths, slopes, and an alignment that included properly spaced alternate and/or point bars. The 30- to 80-year variation was a result of local sediment and slope conditions.

A drainage basin is a closely interrelated system that in time will react throughout the entire basin to any change that upsets its natural equilibrium; however, geologic, man-made, or hydraulic controls may confine the changes to particular reaches. A geomorphic analysis should determine if the system is currently in regime. Nature is not necessarily always right; it may be in transition, trying to regain its natural balance as a result of some abnormal event. Also, nature can often be improved. This is true when the restrictions in the system are of such a magnitude that they resist the controlling forces of the system.

These controls and responses can be discovered and evaluated only by gaining as complete a knowledge as possible of the geologic and soil controls, the hydrologic and runoff patterns, the hydraulic geometry of the drainage basin, and the changes in land use and man's activities that could alter the flows and the sediment loads.

What can be done to regain flood and navigation control of the Lower Mississippi River? First, we must realize that this dynamic system cannot be regulated by political or selfish interests.

Second, we must look at the current and past plans of regulation and stabilization and determine what alterations can be made to the entire program that can aid in the orderly movement of the coarser bed sediments through the system. This in particular should be initiated with a complete assessment of the present alignment and the type, shape, and location of training structures.

Third, we must realize that certain natural events cannot be stopped and can only be altered within limits. It has taken many

decades to build the present system with its associated problems; therefore, it is conceivable that it will take a long period of time to accomplish a well-planned future program and that the success of that program will be very dependent on funding and flexibility as the river responds to unforeseen circumstances.

Lastly, we must realize that many of the plans and programs now in effect are not going to improve the system and that some drastic changes might be necessary. Maintenance funds to retain navigation and flood control need flexibility during the readjustment period; within limits, the needs of people and property should have a degree of priority equal with that of environment. River engineers, as well as environmentalists, need a much better understanding of the entire system.

It is recognized that the type of cooperation and knowledge necessary is not easy to attain. Extremely long periods of time may be needed to acquire the knowledge and to analyze the problem, yet it is not possible to stand still while this is accomplished.

The Potamology Section of the VXD, Corps of Engineers, has had the unique advantage of being allowed a great amount of time over the past decade to study the river and has gleaned some knowledge that will aid in solving both the navigation and flood problems. In general, the initial work that must be accomplished is two-fold; (1) the orderly movement of bed sediments through the system (this assumes that everything possible is being done to hold all sediments in place), and (2) elimination of the aggradation and flooding problems downriver, particularly below Old River (Red River). Both of these will require alterations in current plans of control and unless these conditions are improved, the problems are going to get worse.

The movement of sediments cannot be stopped, but the orderly movement of sediments can be improved. Suspended sediments move with the magnitude of flow and usually create problems only in an underfit system. That is, one that has reduced flow conditions and is adjusting its geometry to the new flows. The Lower Mississippi River has been subjected to an increase in flows, and its problems are a result of the movement of the bed sediments. To date, these cannot be measured nor analyzed

except in a qualitative manner. But the results of this (bed sediment) movement can be measured and analyzed. These sediments move mostly during the high channel-forming discharges and, therefore, in a series of short steps from high water to high water, so they must be allowed temporary storage areas. This movement can be attained only by uniformly and properly spaced alternate and/or point bars. This spacing can be established now only by construction of training dikes that will assist the river in attaining proper alignment.

It is obvious that the floodplain belongs to the river. All rivers will flood periodically and must have conveyance channels that will allow the floods to pass without increasing the stage of flow. Therefore, the use of the floodplains must be regulated.

The proper use of our environment is important. It is firmly believed that what is best for the river for flood control and navigation is usually best from an environmental standpoint.

The present concept of the design and location of training dikes needs some alterations. Water moves in streamlines, and bars and banks of a natural river conform to these streamlines. Any structure placed in a river must be designed to work with the river. Many of the training structures placed in the past few decades do not conform to this concept. Future structures should be designed along these concepts and should be built in a series of steps in order to allow the channel time for an orderly adjustment.

The problems in the river below Old River could create a disaster. Consideration should be given to the abandonment of the Old River Control Structure by slowly decreasing the flows through the Atchafalaya Basin, the improvement of the main river below Old River, and the probability of building a new outlet to the Gulf between Donaldsonville and New Orleans, Louisiana, building New Orleans into a slack-water harbor.

Another problem that can be currently addressed is the location and possible removal of any structures or craft that may be lodged in the bed of the river. During cutoff construction, several revetments were cut through but not completely removed. Today, these reaches seem to have problems attaining enough depth. Other structures have been

flanked and subsequently forgotten; some of these, such as the old revetment in center channel upstream at Cottonwood Bar (mile 471), are creating a permanent divided flow situation.

Many millions of dollars have been spent on bank stabilization; these banks are ±100 ft high. The riverbed is over 5000 ft wide, and no thought has ever been given to its stability. One of the most important factors in the stability of a riverbed is the relationship of the amount of gravel present that can "armor-plate" the bed, reducing the movement of the problem causing coarse bed sediments. Many of the problems occurring below Old River would not exist if the coarse sediments were retained upstream.

Today, not enough is known about the complicated interrelationships in nature nor are formulas available that will give us quantitative answers. However, knowledge of all natural sciences is rapidly expanding so future plans and programs will need the flexibility of incorporating new knowledge and data as they are acquired and new techniques as they are developed.

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